International Handbook on Emergency Management for Flood Defences

Rijkswaterstaat
Ministry of Infrastructure and Water Management

US Army Corps of Engineers®

Environment Agency

MLIT
Ministry of Land, Infrastructure, Transport and Tourism

International Handbook on Emergency Management of Flood Defenses

Reader interest

Coastal, river and estuarine managers and engineers, flood defence owners, civil engineers, hydraulic engineers, geotechnical engineers, crisis managers, crisis communicators, flood forecasters, patrollers / inspectors, responders, crisis planners, rescue & relief, academics

Keywords

Emergency management, preparedness, response, flood defences, levees, embankments, dams and reservoirs, structures, asset management, coastal, rivers, waterways, lakes, flooding, crisis communication, inspection, early warning, geotechnics, failure mechanisms, emergency measures, logistics, implementation, health, safety and wellbeing, reliability, sharing knowledge, training, exercises, funding

Classification

Availability	Unrestricted
Content	Advice/guidance based on PIME (Principle, Issue, Method, Example)
Status	Subjected to peer review and editor team review
User	Flood defences managers, national authority, local authority, Ministry of Defence, researchers, students

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Foreword

In an era of increasing climate change and its associated risks, flood defences have become an indispensable component of flood risk management strategies worldwide. These defences, ranging from embankments and flood walls to dams and other structures, act as the first line of protection against flooding from rivers, coasts, and lakes. While they provide varying levels of protection, they are crucial in safeguarding vulnerable areas. However, these defences are not without limitations and are subject to wear and tear. In the face of potential floods, emergency measures are essential to ensure the performance of existing flood risk management infrastructure or to mitigate flood risk in areas lacking such infrastructure. Effective emergency management of flood defences is therefore a critical aspect of overall flood risk management.

Emergency management for flood defences is a complex undertaking that demands significant effort and expertise from flood asset managers. These professionals must collaborate with various organisations to navigate dynamic and extreme situations, while also considering local conditions and the multifaceted process of assessment and response implementation. The field is characterized by a diverse range of approaches and responses, each with its own advantages and drawbacks. By fostering international knowledge sharing and collaboration, we can elevate the professionalism of emergency management for flood defences, ultimately leading to more effective and efficient responses.

Until now, there has been no single resource that comprehensively addresses emergency management for flood defences, presenting both underlying principles and best practices. Recognizing this gap, Rijkswaterstaat (The Netherlands), the United States Army Corps of Engineers (USA), the Environment Agency (England), and the Ministry of Land, Infrastructure, and Tourism (Japan) took the initiative to develop this handbook.

Over the past 2.5 years, more than 20 organisations and 70 professionals from over 20 countries have collaborated on this handbook. It delves into governance aspects, the details of processes and activities related to emergency management, knowledge sharing and collaboration, and the justification for funding necessary capacities and competencies.

We are pleased to present this handbook to flood asset managers and their partners worldwide. We are confident that it will contribute to professionalizing their practices and hope that this initiative will also lead to a lasting Community of Practice that continues to inspire and support one another in the years to come.

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Main partners

Other contributing organisations

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CHAPTER 1

Introduction

Key messages:

- **Prepare for Increased emergency management**
- **Support preparedness and response**
- **Prevent or delay defence failure**
- **Guidelines not instructions**

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	6.	Flood defences
Details of Processes and Activities	7.	Communicating for emergency management
	8.	Assessing and inspecting
	9.	Understanding the problem
	10.	Selecting and designing measures
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Figure 1.1: Structure of the handbook

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Note:

The Reader is kindly requested to take note of the Disclaimer on page ii of this handbook.

Chapter title page photograph:

Raising awareness of the public at a Dutch waterboard (courtesy: Guus Schoonewille)

Key messages:

- **Prepare for Increased emergency management.** Emergency management of flood defences is a key element of flood risk management, the importance of which is likely to increase given climate change and the resulting increased frequency of flood events.
- **Support preparedness and response.** This handbook has therefore been developed to support flood defence managers in developing (preparedness) and carrying out (response) a professional strategy for managing flood defences during extreme water levels; flood defences include embankments, walls and self-deploying flood systems.
- **Prevent or delay defence failure.** The focus of the handbook is on preventing or delaying flood defence failure; this involves understanding flood defences, risk, early warnings, inspections, risk mitigation and ensuring health, safety, and well-being of response personnel.
- **Guidelines not instructions.** The handbook provides guidelines and not instructions; it supplements the International Levee Handbook and will need adaptation to local circumstances.

This chapter provides the objectives, origins and focal points of the Handbook on Emergency Management for Flood Defences. It outlines the development process and its contributors, delineates the handbook's scope, offers explicit guidance on using it and identifies the target audience.

1.1 Why do we need this handbook?

Floods present serious threats to society, varying from localised incidents to widespread inundations. The management of flood risk involves various strategies, encompassing prevention, protection through flood defences, spatial planning, and timely emergency response. Flood defences, a critical component of risk management, are typically designed and built to specified protection standards. However, these standards inherently have limitations, as there is always a probability that hydraulic conditions may exceed the design limits or that not all defences meet their standards (in poor condition), failing at loads lower than anticipated. Also in some cases, defences are built without any standards in mind and are far from what is needed.

Whether an event surpasses the protection standard, or defences fail, timely response is crucial to prevent or at least delay failure, thereby reducing or avoiding damages and fatalities. The behaviour of flood defences and the organization of emergency response are complex. The physical processes involved are highly dynamic, and effective response management requires collaboration across numerous disciplines and organizations, adding to the complexity.

The challenge of achieving an effective emergency response that prevents or delays the failure of flood defences, particularly when dealing with multiple defences, is formidable. This challenge underscores the need to develop a handbook for flood asset managers, aiming to professionalise and enhance the capabilities of their organisations, staff and volunteers. Climate change and the increasing frequency of global flood events as well as the resulting disasters (see call-out box) have intensified the demand for such a handbook.

Trends in worldwide disasters

The EM-DAT database, which is widely used to analyse disasters worldwide, clearly shows various trends that underline increases in number of events that need to be responded to (see Figure 1.2 below). Although mortality fractions per event have decreased over the period 1975-2022 for middle- and high-middle-income countries, they are still increasing for low-income countries. Hence this underlines the importance to continue to improve both mitigation as well as preparedness and response capacities and capabilities.

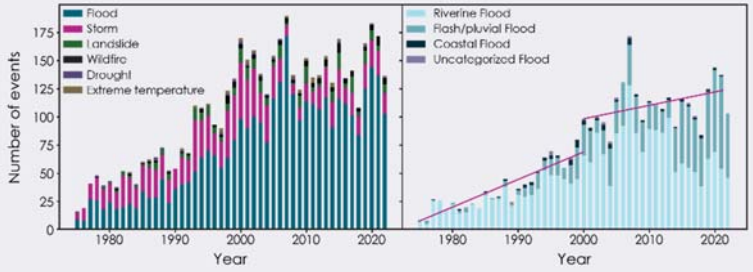

Figure 1.2: Number of disaster events (left) and flood events (right) with one or more fatalities as recorded in EM-DAT for the period 1975-2022 (after: Jonkman, S.N. et al., 2023)

Note that in this handbook, the term 'emergency' rather than 'crisis' or 'disaster' is used. We note the overlapping nature of these three terms as identified by Al-Dahag *et al.* (2016) and illustrated in Figure 1.3. However, the term emergency has been selected as the emphasis of this handbook is on a preparing and implementing a controlled response to flood events. The following definition of emergency by Alexander (2005) is adopted:

"*An imminent or actual event that threatens people, property or the environment and which requires a coordinated response. Emergencies are usually unanticipated, at least in terms of exactly what happens and when and where they take place. However, they can, and should, be planned for.*"

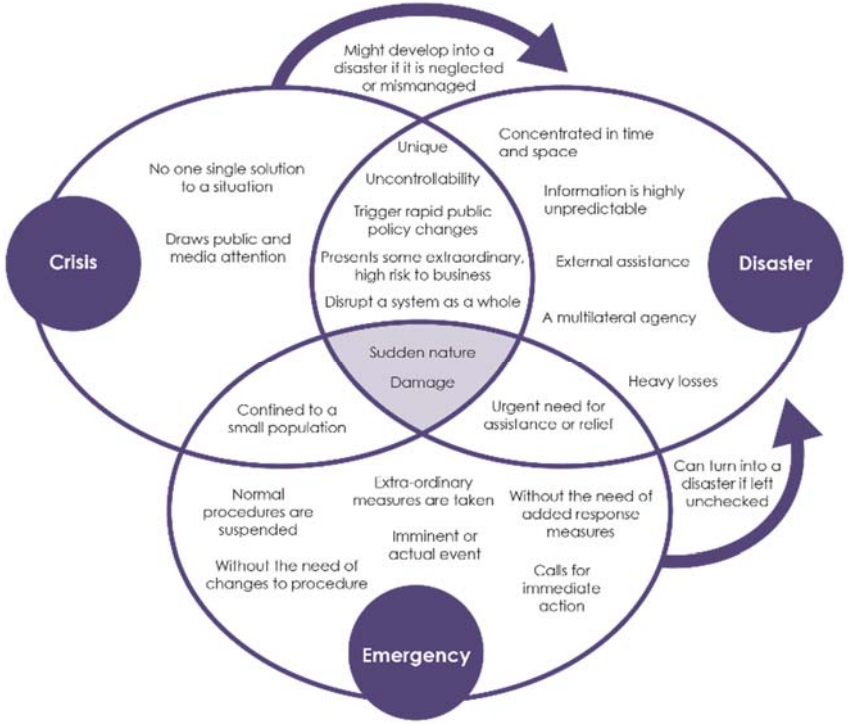

Figure 1.3: Relationships between the concepts of disaster crisis and emergency (after: Al-Dahag et al., 2016)

We also adopt definition of emergency management given by the United Nations (2013) as:

"*The organization and management of resources and responsibilities for addressing all aspects of emergencies, in particular preparedness, response and initial recovery steps. This involves plans and institutional* arrangements to engage and guide the efforts of government, non-government, voluntary and private agencies in comprehensive and coordinated ways to respond to the entire spectrum of emergency needs."

1.2 Emergence of the handbook alliance

The concept of creating this handbook emerged in 2016, during a large-scale flood emergency response exercise in Marken, The Netherlands. The Environment Agency in England, the United States Army Corps of Engineers (USACE) and Rijkswaterstaat of The Netherlands actively participated in this exercise, identifying numerous challenges and shared interests. Recognising the valuable opportunity to learn from diverse experiences, it was apparent that a common framework was essential to understand and translate principles universally. The absence of a dedicated handbook for this critical topic was evident, with existing guidance provided by other initiatives, such as Chapter 6 of the International Levee Handbook (CIRIA, 2013), being very brief.

It was recognised that this shared framework and handbook would have great added value in supporting collaboration, see Vonk et al. (2021). In Europe the EU Civil Protection Mechanism recognises the necessity of collaborative efforts. Many historical incidents have also revealed that floods often surpass the capacity of a single organisation or country, emphasizing the importance of mutual assistance. Notable examples with devastating impacts include Idai (Southern Africa, 2019), summer floods (Germany, Belgium, The Netherlands, 2021) and Pakistan (2022).

1.3 Objectives, scope, and intended use

The main objectives of this handbook are to:

- Establish common principles on emergency management of flood defences, supported by best practices and illustrative examples.
- Assist flood asset managers and other stakeholders in flood emergency management to enhance their organisations during both preparedness and response phases.
- Use language that is common and understandable to all, facilitating mutual assistance and shared learning.
- Plus, additional underlying objectives, including to:
    - Provide clear frameworks and guidance which also provide the context for specific topics.
    - Distil principles, issues, methods and examples related to flood emergency management from existing guidance, recent research and practical experience.
    - Facilitate a common understanding through standardised definitions of terms (see Glossary), notations and acronyms.
    - Identify areas for potential collaborative research over the next five years to enhance the collective knowledge base (see Chapters 15 and 17).

The handbook centres on flood defence emergency management, emphasizing actions flood asset managers can plan and undertake when conditions exceed defence standards or defences fail. To

provide some context for the detailed discussion of preparedness and response, the other aspects of emergency management – rehabilitation and recovery (including build back better) as well as prevention and mitigation (see Figure 1.4) - are briefly discussed in Chapter 2.

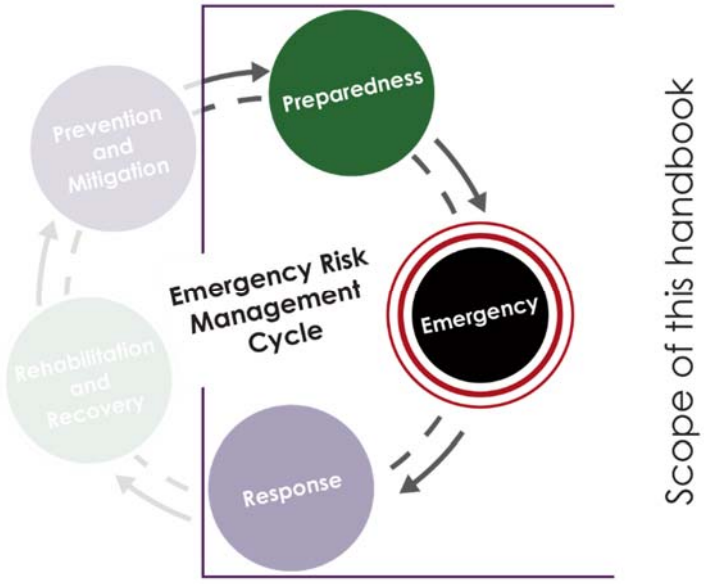

Figure 1.4: Emergency management life cycle, showing scope of the handbook.

The handbook addresses key considerations for effective emergency management of defences, including readiness and preparedness. The focus is mainly on earthen flood embankments, but flood walls, self-deploying flood systems, and water retaining structures (e.g., sluices, locks, culverts) in various settings are also addressed. Complex structures like storm surge barriers are not covered.

Flood threats considered include storm surges and high river discharges caused by precipitation, snowmelt, and flash floods. Pluvial flooding and non-hydrological triggers (earthquakes, tsunamis, landslides) are excluded.

The scope of the handbook is about the right side of Figure 1.4, i.e. preparedness and response. The handbook concentrates on measures to prevent or delay flood defence failure during emergencies (see example in Figure 1.5). Preparedness involves understanding flood defences and the area they surround, including: inspections during or in anticipation of high water, early warnings, failure mitigation, and ensuring health, safety, and well-being of response personnel. This then paves the way for the actual response, which involves understanding the challenges at hand, setting the right priorities and managing the logistics and actual implementation. Response also includes monitoring the situation and adapting where and when needed.

Figure 1.5: Emergency erosion protection to an inner slope of a flood embankment (courtesy: Eric Huijskes)

Emergency management is not the same as flood risk management, which is focussed on improving the longer-term situation, but the two are closely related. For example, information on failure mechanisms and the likelihood of defence failure is relevant to both activities.

The handbook is intended to be used in the preparedness phase (sometime known as the 'cold' phase) and should be used to help prepare the flood defence manager to be able to provide effective management during a flood risk event (both preparedness and response phases). The handbook provides commonly accepted principles and uses commonly accepted language.

The handbook is not:

- A recipe book, where it is only necessary to follow the steps described.
- A handbook from which ready-to-use concepts may be taken and applied immediately in a specific setting.

Use of the handbook should always be undertaken with care. The reader should always be critical when using it and should always think how it ties into the situation at hand.

1.4 Structure of the handbook

The structure of the handbook is as follows:

Chapters 2, 3 and 4 are overarching and provide a general description of the emergency management life cycle (Chapter 2), and, in particular, the preparedness phase (Chapter 3) and the response phase (Chapter 4). These are overview chapters which also discuss the governance of flood-emergency management.

The scope and focus of the handbook are given in Chapters 5 and 6: the flood threats to be considered (Chapter 5) and the types of flood defences (Chapter 6) which the handbook covers.

Chapters 7 to 13 focus down onto the details of the process and activities required to deliver emergency management: communication (chapter 7), assessments and inspections (chapter 8), understanding the problem (Chapter 9), techniques for emergency measures (Chapter 10), selecting and designing measures (Chapter 11), logistics and implementation (Chapter 12); health, safety and wellbeing (Chapter 13), and reliability of emergency measures (Chapter 14).

Chapters 15 and 16 describe support activities for emergency management of flood defences describing how one can learn from and help each other (Chapter 15), and ways in which the required preparedness and response can be funded and how can choices be made if funds are limited (Chapter 16).

Chapter 17 invites readers to use the handbook actively in improving processes and procedures within their own organisations and to collaborate with others in further developing the international state of the art.

Table 1.1: Structure and contents of the handbook

	Ch	Title	Scope of chapter and main topics
Overview (incl. Governance)	2	Overview of emergency management of flood defences	Framework, organisational aspects, policies, planning, communication, international organisations
	3	Preparedness	Components of readiness and preparedness, understanding risk, community engagement, awareness
	4	Response	Components of event & crisis management, escalation procedures, decision making, multiple disasters
Focus areas	5	Flooding threats	River flooding, flooding from sea, pluvial flooding, lake floods, flash floods; implications for vulnerability

	6	Flood defences	Levees / dykes, dams, barriers, structures with flood defence function, demountable and temporary defences
Details of processes and activities	7	Communicating for emergency management	Risk communication, crisis communication, focus is on communication between professionals
	8	Assessing and inspecting	Forecasts, warnings, action triggers and thresholds, regular inspections, damages, staffing, equipment
	9	Understanding the problem	Understanding of the performance of flood defences, including failure mechanisms and fragility curves
	10	Techniques for emergency measures	Descriptions of techniques (e,g. sandbags and other barriers) that can be employed to deliver measures as an emergency response,
	11	Selecting and designing measures	Discussions of measures that can be implemented to either removing the threat of failure or provide an enhanced flood defence. (Note: other measures that are not directly related to flood defences such as evacuation are out-of-scope and only briefly mentioned.)
	12	Logistics and implementation	Organisation, availability, needs, timing, constraints, planning, software and hardware related to communication, navigation and transportation, remote sensing, aerial surveillance
	13	Health, safety and wellbeing	PPE, protocols, standards
	14	Understanding where it can go wrong	Fault tree analyses, understanding the process, human factor
Supporting essentials	15	Sharing knowledge and collaborating	Exercises, Training, Education, EU Civil Protection Mechanism, community involvement
	16	Justifying the required funding	Streamlining funding, how organised, how to justify, how to prioritise
	17	Making it work	Future, innovation, updating the handbook.

1.5 Target audience

The primary target audience of this handbook (see Figure 1.6 and Table 1.2) consists of flood defence managers responsible for keeping their flood defences in a good condition during floods (as to prevent water to inundate the hinterland). Although there will be variations from country to country in the governance arrangements for flood risk management, the primary target audience can therefore be defined as including:

A1: operational staff conducting inspections and early warning.

A2: advisors and risk experts who can define the probability of flood events given the situation in the field and define the measures to be executed.

A3: those operationally involved in the response (e.g. responders, contractors), mainly aimed at preventing floods and preventing failure of flood defences.

A4: flood defence managers, including those involved in policy and in crisis management, that are keen to safeguard the integrity of their flood defence assets.

The flood defence manager cannot realise this alone. Generally, the flood defence manager is supported by other organizations (secondary target audience) that are responsible for either operational matters (B1) or strategic/management matters (B2) e.g. evacuation of the public and avoiding damage; such organisations need to have this knowledge as well. The handbook will be of interest both to these groups and also to researchers and students in the disciplines involved.

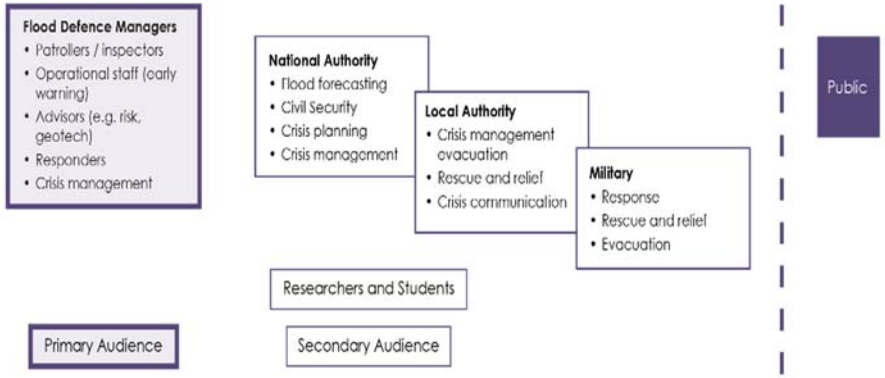

Figure 1.6: Primary and secondary target audience of the handbook

Within the following table an overview is given of which chapters are relevant to which target audience, distinguishing between high (H), medium (M) and low (L) relevance.

Table 1.2: relevance of chapters for various audiences

Ch	Title	A1	A2	A3	A4	B1	B2
2	Overview of emergency management of flood defences	L	M	L	H	L	M
3	Preparedness	M	M	M	H	L	M
4	Response	M	M	M	H	L	M
5	Flooding threats	M	L	M	M	L	H
6	Flood defences	M	L	M	M	L	H
7	Communicating during emergencies	M	M	M	M	M	H
8	Assessing and inspecting	H	H	H	M	M	M
9	Understanding the problem	H	H	H	L	L	L
10	Techniques for emergency measures	M	H	H	L	L	L
11	Selecting and designing measures	M	H	H	L	L	L
12	Logistics and implementation	H	H	H	M	M	M
13	Health, safety and well being	H	M	H	M	M	M
14	Understanding where it can go wrong	M	H	M	M	L	L
15	Sharing knowledge and collaborating	H	H	H	H	M	M
16	Justifying the required funding	L	L	L	H	L	M
17	Making it work	M	M	M	H	M	H

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CHAPTER 2

Emergency management of flood defences

Key messages:

- **Adopt a systems-based approach**
- **Customise the approach to the situation**
- **Develop a strong organisation**
- **Support diverse responses**

Figure 2.1: Structure of the handbook

Other places to find information on the topics of this chapter

Chapter 3: preparedness phase, i.e. one of the quadrants of the emergency cycle

Chapter 4: response phase, i.e. the subsequent quadrant of the emergency cycle

Chapter 5: causes of floods that are considered

Chapter 6: an overview of the types of flood defences that are considered

Chapter 7: insight into the (organization of) communication needed for and during a crisis

Chapters 8 to 12: details of the process, starting from early warning and inspections, to assessing potential failure mechanisms, to selecting emergency measures as well as sorting out the logistics and implementing the measures during an event

Chapter 13: health, safety and wellbeing being of utmost importance for any response provided; the need to embed this in the policy and culture of the flood asset manager's organization

Chapter 14: the role of reliability analysis in understanding how to improve emergency management

Chapter 15: working together as well as training, exercising and knowledge management

Chapter 16: justifying the funds for the needed capacities and capabilities

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Note:

The Reader is kindly requested to take note of the Disclaimer on page ii of this handbook.

Chapter title page photograph:

Understanding high-risk situations with a system that monitors the water levels of multiple rivers simultaneously (courtesy: MLIT)

Key messages

- **Adopt a systems-based approach.** A systems-based approach is required to best manage ongoing flood risks and potential emergencies. Understanding the total system of water sources, flood defences and consequences will help to be able to act in time and be effective.
- **Customise the approach to the situation.** Every flood emergency situation is unique requiring a customised approach, consistently applied. Response, flood fighting and recovery will require a high degree of adaptivity to face the challenges of protecting the hinterland (population, infrastructure, and all other assets at risk).
- **Develop a strong organisation.** Given the devastating consequences of floods, a well-prepared and trained flood emergency management organisation is essential. Strong governance and clear decision-making processes are required to sustain an enduring system.
- **Support diverse responses.** Governance arrangements for flood emergency management should be efficient and effective and support diverse arrangements to absorb and recover from a flood emergency, not completely relying upon the engineered flood defences.

Chapter 2 sets the scene for this handbook, emphasising that emergency management of flood defences must commence well ahead of potential flood emergency situations. As shown in Figure 2.1, the chapter has the closest relations to Chapters 3 (Preparedness) and 4 (Response). It describes the emergency management cycle with the distinct phases of preparation, response, flood fighting and recovery. Different (international) frameworks and examples of governance are described.

This chapter shows the importance of flood risk management and the emergency management cycle to provide a holistic picture. This information is followed by some practical approaches, such as governance, international support and international coordination. Effective preparation ahead of a flood emergency situation is measurably enhanced by adequate early warning via forecasts and expectations of the impact of the flood.

2.1 Flood risk management context

Floods cause immense impacts on the lives of people, animals, eco-systems and economy. However, emergency management of flood defences should always be understood in the overall context of the range of approaches available to manage flood risk.

2.1.1 Flood risk

Risk is a measure of the probability and severity of undesirable consequences or outcomes. In chapter 3, flood risk is defined as being a function of the probability that a flood event will occur, and the consequence associated with that event. In other words, flood risk = f (probability x consequence).

A useful conceptual approach for understanding flood risks is the commonly adopted Source-Pathway-Receptor-Consequence (SPRC) model (See Figure 2.2). This is a simple conceptual model, originating from

environmental pollution management, for representing the flooding systems and processes that lead to various consequences.

Figure 2.2: Source-Pathway-Receptor-Consequence conceptual model (after: Sayers, 2017)

- The hazard or source is the extreme precipitation, water levels and flows in rivers, storm surges etc. that may pose a threat to the receptor.
- The receptor is the entity that may be harmed, i.e. the people, flood plain properties or habitat.
- The consequences is the measure of the harm caused (casualties, loss or damage of properties, economic, social or environmental disruption).
- Between the source and the receptor is the pathway the hazard takes to reach the receptors (flood routes , natural or man-made flood defences etc.). The pathway is often where the likelihood of an adverse outcome (e.g. flood defence fails) can be assessed.

2.1.2 Flood risk management

In the FLOODsite Report T32-04-01 flood risk management is also defined as a "Continuous and holistic societal analysis, assessment and mitigation of flood risk." As explained further in Chapter 3, flood risk management aims to reduce the probability of the hazard occurring or by managing the consequences of the hazard if it does occur. Reductions of the flood probability mostly involve

- Physical measures either to prevent or abate the flood, or
- Measures, including flood defences, which control the probability of the flood reaching the affected populations and properties.

Reductions of the impact of the hazard may involve physical measures to control flood patterns or to flood proof buildings, but mostly involve the following:

- Adaptation and regulation of use of the flood-prone area using regulatory instruments;
- Redistribution of flood impacts using financial instruments, such as insurance;
- Emergency management comprising both preparedness and response.

The country's policy, type of organisation, the risks and the available means (capacity and funds) decide which type of flood risk reduction measures are most appropriate. Where the unacceptable consequences of a flood exceed the value of the investments that must be done to mitigate them, a proactive strategy is advised. In other situations, a more reactive strategy can be more effective.

To determine the strategy at a regional or local level, a risk assessment should be carried out periodically. This should be aimed at deciding on the appropriate balance of investments, for example:

- To invest in flood defences with a very low probability of failure (meaning that emergency management is rarely needed), or

- To accept higher probabilities of defence failure but have a well-organised and trained emergency management organisation.

2.1.3 Flood defences as part of flood risk management

If a decision is made to include flood defences as part of the flood risk management strategy, the level of residual risk associated with those defences that is acceptable may be laid down in national, regional or local policies or be driven by project-specific economic considerations. The adopted approach is typically either

- Standards-based, defining on an equity basis the minimum level of protection that various groups of individuals are entitled to.
- Utility based, whereby the level of protection provided by a portfolio of risk reduction measures (in terms of the benefits of avoided injury or economic detriment) is compared to the cost of that portfolio of measures.

In most cases, since these decisions are mostly funded by public money (taxation), a cost-benefit analysis is generally required to decide what level of protection against flooding should be adopted.

These risk considerations then lead to an implicit or explicit level of flood water and/or rate of wave overtopping which is considered in the design. To ensure that the value of the investments made to arrive at the level of the agreed protection is maintained for subsequent generations after the flood, governments may choose to enshrine these levels of protection in policies or even in legislation.

Given the risks and available means (budget), a country/region can decide to choose a very high standard of protection against floods (e.g. probability of a disaster by floods with a return period of one on the very thousand or ten thousand years). Alternatively, it can also choose lower standard of protection, with the chance every five or ten years that a flood happens which will overtop the defences, but rely mainly on well-trained emergency management organisations to control the consequences of flooding. This means that the policy about flood risk management also defines the strategy for organising emergency management.

The Bowtie Method

The Bowtie Method (Figure 2.3) is one way to make an assessment of the relative merits of various measures to control flood risk (see for example Li et al., 2023). In the SPRC model, the "event" in the middle of the bowtie is most often related to activation of flow through the Pathway (e.g. following defence failure).

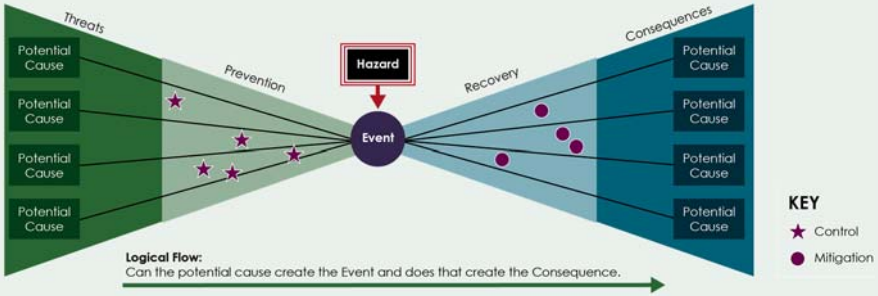

Figure 2.3: Conceptual diagram of the Bowtie method (after: Julian Talbot, 2018)

The repeating sequence of flood risk management thinking and activity in relation to flood defences includes the following steps:

1. The current national policy on flood risk management is periodically reviewed and translated into approaches to defining the maximum acceptable probability of flood defences overtopping or failing (mostly as expressed in a probability of once in the "x" year).
2. Given the acceptable probabilities of inadequate defence performance, assessments are made to identify whether the flood defences meet these requirements

3. Once the assessments have been completed, necessary reinforcement programmes are initiated, and/or routine asset management is continued.

2.1.4 Types of flood defences

Chapter 6 sets out the range of flood defences that may be employed as part of flood risk management. Considering again the SPRC model, the focus of this handbook is on flood defences that act as barriers to retain water and prevent it passing through the pathway to the receptors. These pathway barrier flood defences include flood embankments, flood walls and temporary and demountable flood defences. Flood embankments are a particular focus of this handbook since their vulnerability means that they are often the focus of much emergency activity.

Other types of flood defences discussed in Chapter 6, but not extensively thereafter, include those associated with watercourses

- To detain flood flows (dams and reservoirs);
- To control the rate of flow along watercourses (locks, weirs, river restoration etc); or
- To divert that flow (floodways, flood diversion tunnels).

2.1.5 Threats to flood defences

As described in Chapter 5, floods are basically of four different types:

- High river discharges caused by large amounts of precipitation and/or snow, and high-water levels in water systems fed by those rivers;
- Storm surges and high wave loads along the coast and some large lakes;
- Intense precipitation on an often-smaller spatial scale than the previous two types, sometimes called flash floods, causing rapid direct flooding of lower lying areas;
- Rising groundwater tables, leading to local or regional slowly developing floods.

However, since flood defences are most commonly used to exclude floods along rivers and the coast, the first two types of flood are the focus of this handbook.

Other, non-hydro-meteorological causes like earthquakes (leading to tsunamis or landslides), structural failures or terrorist activities are not discussed in this handbook. Chapters in this handbook can however be helpful for action even in those situations.

Figure 2.4: Four types of flooding

Each of these types of flood event have different characteristics, like:

- Lead time - the time between the issuance of an early warning and the moment that the storm surge or high water or wave actually loads the flood defences. Some floods can occur within a few hours; others may have a long lead time of days or even weeks (in the case of very large rivers).
- Speed and magnitude of water level rise and fall, and duration of high-water level. There may be a lot of variation here:
  - The water level may rise very rapidly (in a few hours), but it can also drop very suddenly;
  - The top of the peak may be relatively low and water levels may raise slowly over days, but the resulting water level can stay for a prolonged time (even weeks).
- The water velocity and wave conditions associated with the flood,
- Coastal storm surges (including effect of the highest tides). These can often be forecast a few days ahead, but the pathway of the storm (whether tropical or extra-tropical) can change from hour to hour. Where the storm eventually will land on the coast and cause the most flooding is often hard to predict.
- Coincidence of phenomena. High river discharges and water levels may coincide with severe weather conditions like storm, extreme rainfall, low temperatures, etc. But high-water discharges can also occur during very calm even warm and sunny weather conditions.

Flood defences will be threatened by these flood characteristics in different ways:

- Water may simply overflow or overtop (waves) the defence without causing damage to the defence.
- Overflowing/overtopping water may cause erosion on the landside of the defence.
- High water velocities and or wave conditions may directly damage the waterside face and crest of the defence.
- High water levels may cause seepage through or beneath the defence causing erosion.
- High water levels and raised internal water pressures inside the defence may initiate mass instability.

As explained in Chapter 5, the way that flood defences are threatened will depend on the various flood characteristics. The characteristics of the flood combined with the threats will affect the approach to creating and maintaining the flood defence; this includes the approach to emergency management.

2.2 Emergency management of flood defences

Emergency management is one measure in the flood risk management portfolio discussed in the previous section that can be adopted to reduce the effect of a flood hazard. It can be defined as comprising:

- The identification of a flooding threat when the nature or magnitude of natural or man-made hazards exceeds the capacity of existing mitigation measures.
- The setting up and implementing policies and procedures to defend, mitigate and prevent an emergency.

Every flood emergency is unique, not only because of the specific hydro-meteorological characteristics of the event but also because every flood risk system has unique physical characteristics, including its topography, mix of properties, climate and water systems (see Chapter 5 for more details) and the mix of any defences (see Chapter 6 for details). In this handbook we use the word emergency rather than crisis or disaster to describe an event

In systems where flood defences retain flood water, all kinds of hydraulic forces develop on, inside and underneath these structures. These forces can lead to overtopping or breaching of the flood defence and

subsequent flooding of adjacent areas. No matter how well designed, a flood defence which leads to a zero risk of flooding cannot be achieved. So, there is a need for up-to-date and properly trialled emergency management plans primarily focussed on the two situations in Table 2.1 below.

Table 2.1: Flood defence situations to be managed during an emergency

Situation 1: A hydraulic load is likely to exceed the design levels and hence the flood defence will be overtopped.	Situation 2: The flood defence structure will fail during the flood, often at a hydraulic load less than that for which the defence was designed.
Flood defence does not breach	Flood defence breaches
Risk is residual accepted risk	Risk is incremental risk or flood defence risk
Such a situation can generally be predicted a few days or hours before and actions can be prepared and performed in time.	Such a situation can happen during the flood emergency and is much harder to manage.

In addition to these situations, emergency management also needs to address:

- Terrorism, both physical attacks on the defences and cyber-attacks which interfere with emergency communications operations. Hacking of vital computer systems can cause failure during closing or opening processes of locks, gateways, storm surge barriers, etc. For this reason, if possible, operating systems should not be connected to open networks.
- Misinformation and disinformation. Deliberately spreading false news about failure of flood defences can cause unnecessary anxiety among the people living behind the flood defences. This means that fact checking is always necessary. There are even situations that the flood defence operation teams have had to carry out their work incognito because they were threatened by angry individuals. Staff should therefore be instructed how to work safely. For example, the logo of the organisation one works (on jackets, cars, boats, etc.) for should be able to be covered.

2.2.1 Emergency management cycle

To set the scene for Chapters 3 (Preparedness) and 4 (Response), the concept of the cycle for emergency management of flood defences is explained here. Figure 2.5 (first introduced in Chapter 1) shows the cycle, representing a continuous process of preparedness, response, recovery, and mitigation. The cycle will involve multiple actors, each with their responsibilities, as discussed in section 2.3.1. Each of these phases are now outlined.

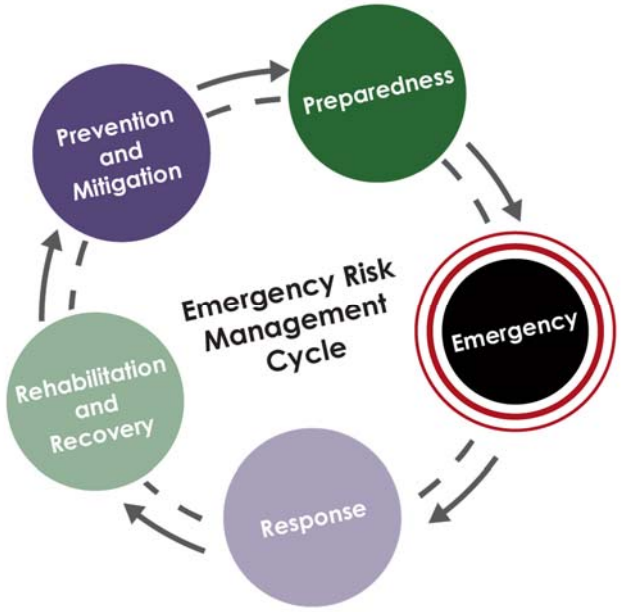

Figure 2.5: Emergency Management Cycle

Preparedness

Flood defence managers are generally responsible for assuring that the flood defence (system) performs as intended. Coordination and planning

with all affected stakeholders is essential to achieve the optimal risk reduction. This is discussed in chapter 3 of this handbook. To summarise, it is about knowing and understanding the managed water and flood defences system, the location of potential weak spots and having a forecast and an early warning system (EWS). In the preparedness phase ideally:

- Emergency action plans should be written, trialled, evaluated and put into practice periodically.
  - These plans should provide a user-friendly protocol for managing emergencies in a coordinated and effective manner.
  - The staff involved in the emergency should know how to act and have the means (e.g. equipment) to act during an emergency.
  - Training should be carried out together with all affected stakeholders to help to ensure optimal risk reduction during an emergency.
- Staff involved should take care of their own health, safety and wellbeing and of others potentially involved (chapter 13).

Response

The response phase commences when an emergency has been declared and the emergency action plan is put into practice. In flood emergency situations flood defence managers should respond to mitigate risks as much as possible. For the flood defence manager, the activities range from actions taken to repair, strengthen and/or raise (if not harmful to some other area) the flood defence as well as supporting activities (e.g. evacuation) by other emergency responders within the area served by the flood defence. Activities in the area served by the flood defence often include coordinated action between the flood defence manager, flood risk management authorities and other stakeholders.

The response phase will be discussed in more detail in chapter 4. But, in summary:

- For the flood defence management organisation, actions to assess and analyse the risks are undertaken. These analyses lead to defining and designing the necessary emergency measures. The resulting activities include inspection, repair, strengthening and/or raising (if not harmful to some other area) the flood defences.
- Other emergency responders within the protected area such as firefighters, law enforcers and emergency medical personnel, and search and rescue (land or water) teams are responsible for evacuation and continued availability of vital infrastructure such as power supply, communication services, evacuation routes, etc.

Recovery

Recovery typically begins as soon as the flood emergency has subsided. After a flood emergency, flood defences can be damaged or weakened. Since the next flood might occur within a few weeks or months, activities aimed at returning the flood defence to full readiness and restoring the affected area to a normal state should be commenced as soon as possible. If there is insufficient time to carry out a full repair, temporary measures may be required to return the flood defences to sufficient readiness and to restore the affected area to normal conditions. Given the fact that budget is always limited it is advised to start with a damage and loss assessment; this will help to prioritize urgent actions and ensure the effective use of available funds.

More broadly, recovery involves individual, private sector, non-governmental, and public assistance programmes that focus on restoring economic activity, rebuilding community facilities and housing, addressing long-term relocation and care of the affected population, re-employment, repair of critical infrastructure, and other measures for community restoration and economic recovery.

Mitigation

A flood emergency also exposes the weak spots in the flood defence systems (lessons identified). The damage and loss assessment carried out during the recovery phase can be used to translate lessons identified to

lessons learned. This will help to prioritize mitigation actions that will control or reduce existing risks. Thus, mitigation focuses on preventing hazards from developing into emergencies in the future as well as reducing the effects of emergencies when they occur.

Mitigation measures can include identifying ways either to act earlier during a flood or to adapt the system after a flood. 'Building back better' is a philosophy of learning from emergency situations in the (recent) past and adapting the water or flood defence system in such a way that the probability of the future failure and damage is reduced. Examples of such measures would include improving the functionality of the flood defence by increasing the height, width, or bank protection.

Activities within the response and recovery phases include:

- Detection of the likelihood of a flood forming (hydrometeorology).
- Forecasting future river flow conditions from hydro-meteorological observations.
- Draining the water via river or canal systems as much as possible.
- Retaining the surplus of water by flood defences.
- In the event of an extreme situation when flood defences might fail, or the hydraulic load might exceed its design limits
    - Emergency management of the flood defences themselves.
    - Issuing warnings about the emergency to the appropriate authorities and the public on the extent, severity and timing of the flood.
    - Responding to the emergency by the public and the authorities.
- Initial recovery after the flood emergency is managed.
- Immediate inspections.
- Repair of damaged assets, making them flood-proof again (that can happen again within a few weeks or months). Note that this repair may require 'building back better' where water system flaws are identified; such activities would then not be part of the initial recovery and become longer-term mitigation actions during that will depend on governmental decision-making and funding.

The preparedness phase is discussed further in Chapter 3 and the response phase in Chapter 4.

2.2.2 Preparedness and response plans

For each catchment area a tailor-made plan should be prepared: there is no "one size fits all" preparedness and response plan. There are some basic principles to follow when preparing such plans:

- Early warning systems (for example weather forecasts) are important as they give time to prepare for a flood emergency. Such early warnings should be translated to expected hydraulic loads like river water levels, storm surges or surface water.
- Knowledge of the condition of the flood defence systems helps to assess where there will be a significant probability of failure of the flood defences. This helps to prepare and execute the emergency measures to protect property or vital infrastructure in the hinterland.
- Inspection (if possible) of the flood defences during or directly after a flood emergency and undertaking of the appropriate measures to repair detected anomalies; the flood defences can be weakened by the hydraulic loads and should be prepared in time for a subsequent event that might happen at short notice.

Overarching principles are:

- Taking care of health, safety and wellbeing of flood-fight staff;
- Effective emergency communication to identify the right response to the risks to which people are exposed; and
- Working together between the different organisations responsible.

So, preparation, response, flood-fighting and recovery will demand a high degree of adaptivity to face the challenges and protect the hinterland (population, infrastructure and all other assets at risk). To become adaptive, it is important to prepare an organisation for the reasonable worst case.

2.2.3 Classification of flood events

In Chapter 3 and Chapter 4 the necessity of understanding the risks that comes with predicted weather or flood forecasts (preparedness) and how to act (response) is explained.

These forecasts are issued so that stakeholders, like regional water authorities and municipalities, can prepare for action. Collaboration between the different stakeholders in an as early stage as possible is essential. All actions should fit together in time to give maximum protection to the people living behind the flood defences. For example, using the same infrastructure at the same moment for evacuation of people and cattle out of the area as for the transporting of flood protection equipment into the area, will most certainly lead to a disaster.

The simplest way to implement warnings is through a warning scale or classification, which seeks to convey the level of urgency of an event, with the point on the scale changing as the event evolves. The warning scale is often translated into a severity colour code with a text attribute that ranges from none, to low, to moderate, to major threat. The severity level is selected based on trigger points or exceeding certain thresholds (like certain river discharges), each corresponding to a colour code. Tables 2.2 and 2.3 provide typical examples of a classification process showing defined thresholds against which decisions to escalate or deescalate an event can be made efficiently.

Warning scales also help to reduce the potential for misalignment of processes particularly between organisations. With all organisations involved sharing the same classification system, there should be minimal risk of misalignment. Decision-making and associated roles and responsibilities align with these classifications as will interfaces between organisations collaborating to mitigate flood effects.

It is normal to classify and reclassify events as they evolve. So, while Figure 2.6 implies a progressive process from top to bottom, once initiated, the process can involve many loops as the situation is monitored further and changes, particularly from Step 2 to Step 4. Once an event reaches an elevated state (e.g. Orange or Red) a complementary classification system is likely to be used to indicate the relative status of the flood, including its magnitude, the ability of flood defences to mitigate the risk and any anticipated consequences. The divisions between event magnitude are defined during the preparedness and readiness phases and will likely be aligned to specific triggers described in Chapter 3. A flood emergency may therefore escalate up classifications due to magnitude or if flood defences become compromised.

Table 2.2: Event Classification Matrix (adapted from: Valley Water California, 2022)

Level	State	Trigger Condition
Preparedness	Basic stage of readiness that is the typical condition for most of the time	River stage within normal limits with no flood triggers expected to be exceeded in the next 72 hours.
Monitoring	Heightened monitoring and associated inspections. Initial pre-event preparedness may occur.	River stage within normal limits but one or more flood triggers are expected to be exceeded in the next 72 hours.
Watch	Event management process likely to have been initiated with associated actions including stakeholder engagement.	One or more flood trigger likely to be exceeded within 24 to 72 hours. Rainfall triggers may already have activated.
Warning	Management is active. Response actions will be occurring to seek to avoid an emergency.	One or more triggers activated with flood levels above or anticipated to exceed specific flood classification levels in the near future.

2.2.4 Knowledge: information and skills

Knowledge is considered more than just having information (guidelines, emergency plans, data bases, etc.). Knowledge is the product of Information, Skills, Experience and Attitude (behaviour). In this chapter the information and the needed skills are discussed.

Whilst every country or region will have their own disaster response processes and plans and appropriate organisation, roles and officials, the skills and knowledge needed in a flood emergency organisation are universal. An overview of skills and functionality that can be associated with the various roles is presented in Table 2.4.

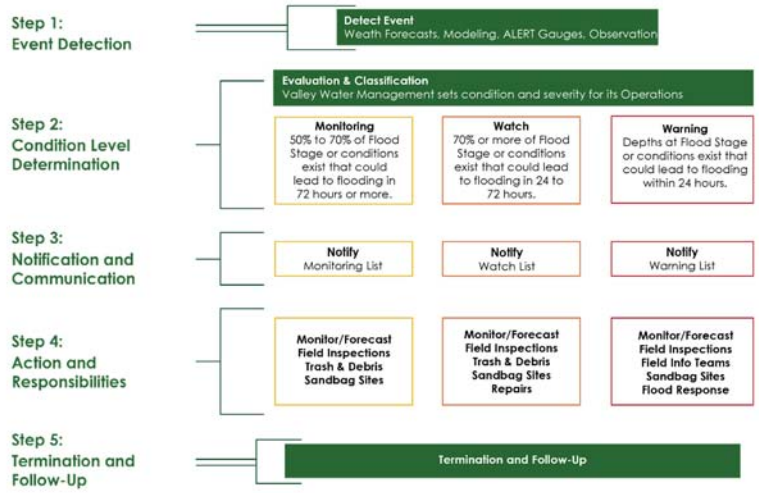

Figure 2.6: Example of an event management process (after: San Francisquito creek Emergency Action Plan Quick Guide EAP)

Table 2.3: Example of risk classification in the Dutch National High Water and Floods Script

Change to next colour code	River system and location					
	Rhine, Lek, Waal		Lower Meuse		Limburg Meuse	
	Lobith **Water level** (m + Main Sea Level)	**Lobith Discharge** (m3/sec)	**Mook** **Water level** (m + Main Sea level)	**Sambeek** **Water level** (m + Main Sea level)	**St. Pieter** (m + Main Sea level)	**St Pieter** **Discharge** (m3/s)
Green	Normal situation, no flood risk situation					
Yellow	12,00 (summer) 13,00 (winter Several times a year	4200 (summer) 5260 (winter	-	-	44,45 Several times a year	700 Several times a year
Orange	15,00 1:5 year	8073 1:5 year	9,78 1:2 year	12,16 1:2 year	46,40 1:5 year	2000 1:5 year
Red	16,50 1:100 year	11689 1:100 year	11,38 1:40 year	13,34 1:40 year	47,45 1:25 year	2600 1:25 year
Design level	18,00 1:1250 year	16000 1:1250 year			48,30 1:250 year	3400 1:250 year

Table 2.4 Overview of information (left) and skills (right) needed in a flood emergency organisation

Information	Skills
The availability of response capacity and capabilities like staff, experts, contractors etc.	Organizing (forming and managing teams)
Accessibility of the area, logistical challenges Maps of local situation (geographical)* Inundation maps*	Mapping (visualizing the flood extent and dynamics) Inspecting (assessing and understanding failure mechanisms) Data coordination (collecting and processing of data) Information coordination (bring information together, providing situational awareness, coordination)
Design criteria of the water works including the flood defences* Geotechnical and geophysical data* Pore pressure measures (time related during the increase of the hydraulic loads) Movement of flood defence in vertical or horizontal direction ((time related during the increase of the hydraulic loads)	Forecasting and predicting (understanding future conditions and their probability, translating this to best estimate / reasonable worst case) Modelling (understanding the water system)
Design criteria of the water works including the flood defences* Geotechnical and geophysical data* Pore pressure measurements (time related during the increase of the hydraulic loads) Movement of flood defence in vertical or horizontal direction ((time related during the increase of the hydraulic loads)	Consequences analysis (assessing and understanding the consequences) Risk analysis (assessing and understanding the risk) Decision making (understanding risk, consequences and pros and cons of options)
Actual condition of the assets* Animal activities (digging holes) in the flood defences Historical data* Inspection data	Operations (understanding the measure and how to implement) Technical expertise (understanding the task at hand and supporting actions) Engineering (selecting appropriate measures, “designing” measures, instructions how to carry out)
Stock information	Logistics (matching availability to needs, organizing implementation) Planning (understanding lead times and planning how to respond, forming team, preparing protocols and plans)
Stakeholders and their needs	Community engagement (before, during and after) Communication (translate information into understandable messages, both internal and external, both pro-active and reactive, managing disinformation)
	Risk based planning of the recovery phase
	Evaluation (PDCA, identify lessons through (independent) debriefs)

2.2.5 Use of scenarios in decision making for emergency management

The impact of a flood emergency is not easy to determine. With many variables like weather patterns, functioning is of the water systems, condition of the flood defences etc., there are many possible outcomes to act on.

Kolen (2013) shows that it makes sense to take uncertainties into account and make explicit use of scenario analysis. People are trained to "be prepared" using the expected. A matrix of time and impact (see below) can be used to define the need for additional scenarios next to the best-case scenarios which are already in use in emergency planning.

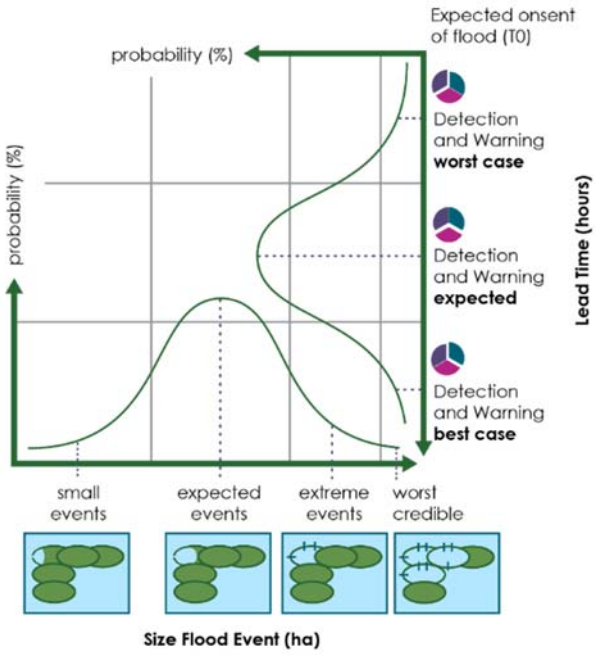

Figure 2.7: Matrix of scenarios based on uncertainty in impact and time (after: Kolen, 2013)

The matrix covers classes that represent all possible (known) scenarios based on a combination of impact and time. The concept of this matrix is shown in Figure 2.7 which (in this example) considers 4 classes of impact and 3 of time.

It can help to focus on three scenarios: the reasonable worst case the most likely case and the reasonable best case. This can help to determine the triggers that can lead to one of them. Perhaps it is possible to take measures to make the path of the scenario towards the reasonable best case. If that is not possible, then it is advised to take the reasonable worst case as the one to prepare the emergency management teams for that scenario. In developing these cases, at least one scenario should assume a limited capacity of emergency services whilst another should assume all measures will be implemented.

The matrix of scenarios can be used during both preparedness and response phases:

- During the preparedness phase, the scenario matric can be used for the identification of possible classes of events and measures and of the different types of evacuation measure (preventive, vertical, shelter in place, rescue, etc.) that need to be prepared. It can be made clear that some measures only work in specific situations (for example, preventive evacuation only results in a reduction of loss of life when sufficient time is available).
- During the response phase the scenario matrix can be used to support decision-making. Forecasts of water levels and the time to onset of flooding can be related to the relevant classes and the probability of flooding in the next days or hours can be determined for these classes. This knowledge can be used to define the evacuation and organization zone and the risk in these areas. For each class, alternative response strategies can be developed as input for top strategic decision making (Kolen, 2013).

2.3 Governance and organisation

This subchapter explains the importance of sound governance to reduce flood risks and to be able to act effectively during floods.

2.3.1 Overview of governance

Governance is the way the rules, norms, and actions are structured, sustained, regulated and held accountable (ICOLD levee committee). It encompasses the system by which an organisation is managed and operated, and the mechanism by which it and its people are held accountable (including ethic). This includes risk management, legal compliance and administration.

Diversity in the arrangement of intervention and management measures enables the problem to be managed at multiple scales and is seen as an important 'fail safe' (Renn et al., 2011, Hegger et al., 2014). The presence of multi-layered institutions also allows for 'scale matching' and to 'improve the fit between knowledge, action, and socio-ecological processes' (Djalante et al., 2011: p4). The following criteria for evaluating the governance of flood risk management have been identified (Alexander et al., 2016; Termeer et al., 2011; OECD, 2015; Thaler & Hartmann, 2016):

- Resource efficiency (Including economic, human (personnel, skills and knowledge) and technological resources);
- Social equity;
- Accountability;
- Transparency;
- Inclusive and participatory decision-making;
- Access to information;
- Procedural justice;
- Acceptability by society.

These criteria can be assimilated into the umbrella notion of legitimacy. An example of how six European countries differ regarding their Flood Risk Governance Approaches (FRGA's) is given in Table 2.5.

As discussed in Section 2.1 above, floods cannot always be prevented through engineered solutions, as defences are not infallible and may not be economically feasible or sustainable in the long-term (Hegger et al., 2014). Therefore, governance for flood risk management should also support the capacity to absorb and recover. This requires sound and efficient governance for flood emergency management, with:

- A robust legal and institutional framework (national / regional / local)
- Well-understood core roles and responsibilities
- A straightforward, clear and properly trialled decision-making process

Core roles relevant to an effective management of an event are discussed in following paragraphs and definition of these is part of preparedness and readiness as discussed in Chapter 3.

Table 2.5: Approaches to flood risks and governance in six countries (adapted from: Matczak et al, 2016; see also Wiering et al, 2017)

Characteristics of (sub-) FRGAs	Netherlands	Poland	France	Belgium	England	Sweden
Diversification & Dominance	Only slightly diversified, Defence dominant	Only slightly diversified, Defence dominant	Moderately diversified, Prevention dominant but defence still important	Moderately diversified, Defence still important	Highly diversified Quite balanced	No specific FRGA, Focus on preparation and recovery
Multi-Sector	Water sector dominant	Water sector dominant	Water sector and spatial planning equally important	Water sector and spatial planning gaining equal importance; water sector still important	Multi-sector involvement & integrated by spatial planning	Multi-sector involvement, but not integrated
Multi-Actor	Public (state dominant)	Public (state dominant)	Public (state dominant)	Public (state dominant)	Public & private	Public & private
Multi-Level	Both central and regional level (water boards)	Central, towards the regional level	Central, towards de-centralized	De-centralized, tendency towards centralization	Central and local level	De-centralized, local level

2.3.2 Key parts of the organisation and their responsibilities

When setting up a flood risk emergency organisation it is necessary to have a decision-making team (or board), tactical or coordinating teams and field teams. The sequence of interactions between these teams is typically as follows:

1. The field teams have the responsibility to detect a potential critical situation as soon as possible or to warn when a flood defence is starting to fail. They report this information to the tactical teams;
2. The tactical teams make analyses and prepare decisions, based on what field teams report from the actual situation in the field. It is inevitable that the tactical teams must prepare decisions based on risk assessments. Often there are limited resources or staff to eliminate all risks and some prioritization is necessary;
3. The decision-making team or board makes the decisions and are accountable for the consequences of the decisions;
4. The tactical teams translate the decisions to clear instructions for the operational activities for the field teams.

As every country or region has its own governmental organization it is not possible to describe one governance system as best practice. Instead, the handbook gives some principles and examples of governance in a few countries as inspiration.

In an emergency management operation, many partners will be involved (Alexander at al., 2016). As well as the main organisations responsible for emergency management of flood defences, other actors and stakeholders may have a role, including response personnel, public safety and health organisations, utilities, government agencies and officials, private companies, and citizens.

The responsibilities for management are likely to be divided between more than one partner organization, although the level of involvement differs for each, depending on the governance arrangements. Each partner will not necessarily participate in every phase of an emergency, but the basic principles are that:

- Organisations should work in close collaboration. This includes:
  - Sustaining communication between them in all phases of the event;
  - Understanding each other's language (technical, societal, legal).
- Officials in each organisation should know and understand each other's roles and responsibilities and formulate the necessary decisions together. Misunderstanding of responsibilities leads to poor decision-making, or potentially worse, no decisions at all
- The decision-making process should be clear and unambiguous. This ensures that each organization is accountable for its actions and the different actions are complementary to the actions of the other organization instead of counterproductive.

In Chapters 7 (Communicating during emergencies), 12 (Logistics and implementation) and 14 (Learning from and helping each other) the importance of understanding how different organisations can work together to during a flood is explained in more detail.

To help the reader Table 2.6 gives an overview of the key elements and how these are organized in four different countries (Japan, Netherlands, United Kingdom, USA). This is followed by call-out boxes in which the arrangements in each country are described.

Flood management systems also need to remain continuously effective even though flood emergency situations may be years or decades apart. Where roles and responsibilities are not actively defined, there is increased risk of the readiness of the system deteriorating over time. To prevent this, it is advised to have clear policy and funding in place. Clearly defining roles and responsibilities assists with sustaining the system over time through training, exercising and knowledge management as discussed in Chapter 15. Clear roles and responsibilities help succession planning and avoid core functions becoming forgotten as organizations change.

Table 2.6 Key elements of Flood Risk Management and Emergency Management governance in four countries compared

Key element	Japan	Netherlands	UK	USA
Decision board	Flood Defence Manager Decision making party. The local government plays this role. The party also ensures coordination with relevant organizations such as the fire department and police.	Regarding flood prevention Decision board chaired by Rijkswaterstaat. Each regional Water Authority (as independent party) chaired by the "dijkgraaf" as CEO. Regarding safety of citizens and properties Ministry of Justice and Security takes over In case of national threat an Interdepartmental emergency management team chaired by Prime Minister	The role of central government is · Department for the Environment Food & Rural Affairs (Defra) – FRM Policy, · Department for Communities and Local Government (DCLG) – Spatial planning Policy · Cabinet Office – Civil contingencies The National Flood and Coastal Erosion Risk Management Strategy for England provides the overarching framework for future action by all risk management authorities to respond to flooding and coastal erosion in England	A tiered and supplementary approach from higher levels of government ensures unity of effort and effective coordination of resources
Tactical Unit	Flood Defence Support Team Supporting team assisting flood defence team. Private companies and NGOs are expected to play this role. This party patrols the safe area, provides logistical support such as making and transporting sandbags, and provides equipment and place to store it to the flood defence team.	Regarding flood prevention · National coordination commission for flood threats, supported by The National Water Management Centre · Back offices at regional water authorities · Emergency Management Team Water defence experts Regarding safety of citizens and properties Safety regions with mayors as chair	The Environment Agency, lead local flood authorities (LLFAs) and internal drainage boards (IDB) are named as Risk Management Authorities (RMA) by the Flood and Water Management Act. They have legal or permissive powers allowing them to do work when it is for flood and coastal risk management.	Local communities are the critical component to flood preparedness and response efforts.
Field teams	Flood Defence Team Team operating physical interventions on the field. This party carries out patrols, inspections and field work in the emergency phase. The team members should be appointed or employed within their communities. This party also carries out training and exercises, maintenance of equipment and tools.	Regional water authorities in the lead Flood Inspection Teams from Regional Water Authorities Contractors for performing necessary (emergency) measures Volunteers from communities (dike army) Ministry of Defence In case of imminent threat for citizen and property the Mayor will take over the lead. Fire brigades, police, health care and Ministry of Defence to support	The Flood and Water Management Act gave lead local flood authorities (LLFAs) in England and Wales the lead role in managing the risk of all local causes of floods. The Act also gave the Environment Agency responsibility for an overview of flood and coastal erosion risk management.	local communities are the critical component to flood preparedness and response efforts.

Japanese approach to governance of emergency management of flooding and flood defences

In Japan, flood emergency response is generally recognized as a self-defence disaster mitigation activity to protect their own community with their own hands. The relevant partners involve not only disaster response agencies, but also a diverse group of stakeholders, including the Self-Defence Forces, police, firefighters, the Red Cross, lifeline providers such as power and water, and local resident. In accordance with the laws and regulations set by the central government, the local government takes the lead in coordinating all the parties involved in carrying out activities in the field. In the event of an emergency, all partners are expected to gather at the location of the emergency to perform the difficult task of saving their own lives and the lives of the local community.

The following core parties are legally defined in Japan.

Flood Defence Manager – the decision-making organisation. The local government plays this role and defines and establishes other core partners, formulates a flood defence plan, and makes most of the decisions related to flood defence activities during normal and emergency phases. The flood defence manager also ensures coordination with relevant organizations such as the fire department and police.

Flood Defence Team – the team operating physical interventions in the field. This partner carries out patrols, inspections and field work in the emergency phase. The team members should be appointed or employed within their communities so that they can use their local knowledge and interpersonal skills to be effective. In this way, local communities can have an active role in protecting their own properties. This partner also carries out training and exercises, maintenance of equipment and tools.

Flood Defence Support Team – a supporting team assisting flood defence team. Private companies and NGOs are expected to play this role. This partner was established in response to the situation of a shortage of flood defence team members and the growing awareness of the public and the business sector about the flood emergency. This party patrols the safe area, provides logistical support such as making and transporting sandbags, and provides equipment and place to store it to the flood defence team.

English governance of emergency management of flooding and flood defences

The governance of English flood risk management is dictated by the Flood and Water Management Act 2010. It clarifies the structures and responsibilities for managing flood and coastal erosion risk in England and Wales, and it defines the roles of Lead Local Flood Authorities. In particular, the Act places a duty on all flood risk management authorities to cooperate with each other.

Roles and responsibilities are set out in National Strategy. The role of central government is:

- Department for the Environment Food & Rural Affairs (Defra) – FRM Policy;
- Department for Communities and Local Government (DCLG) – Spatial planning Policy;
- Cabinet Office – Civil contingencies.

The National Flood and Coastal Erosion Risk Management Strategy for England provides the overarching framework for future action by all risk management authorities to respond to flooding and coastal erosion in England. The EU Floods Directive was transposed into law in England by the Flood Risk Regulations 2009 (still in place post Brexit). Under these Regulations, there are a series of requirements which take place as part of a six-year cycle.

The Environment Agency, lead local flood authorities (LLFAs) and internal drainage boards (IDB) are named as Risk Management Authorities (RMA) by the Flood and Water Management Act. They have legal powers ('permissive powers') allowing them to do work when it is for flood and coastal risk management. Permissive powers reside with the Environment Agency for Main River watercourses, and with the Lead Local Flood Authority (i.e. the Council or a local drainage board) for Ordinary Watercourses, e.g. permissive powers can allow flood authorities to support a riparian owner in meeting their riparian obligations if there is an overriding public interest.

Dutch approach to governance of emergency management of flooding and flood defences

In the Netherlands, flood emergency governance depends on the level of impact of the incident/different levels of the national safety risk classification. The lowest level 1 is a very local single-issue risk, easily managed by the asset owner self. The highest level 5 means a risk with an (inter)national multifunctional impact. The higher risk levels involve upscaling flood risk governance responsibilities. In the lowest level the asset owner can handle the incident alone (or together with the stakeholder), in level 2 also a police officer or a fire brigade will assist, together on location of incident decisions are made to mitigate the risk. At level 3 a mayor of the city at risk will form an emergency management team of stakeholders where the decisions are made, the regional water organization is member of this emergency management team. At level 4 the safety region (a partnership of all mayors of the cities affected by the incident) will take the lead. Finally, at level 5 the Ministers of the different departments will form a national interdepartmental emergency management organisation.

United States governance of emergency management of flooding and flood defences

In the United States, local communities are the critical component to flood preparedness and response efforts. A tiered and supplementary approach from higher levels of government ensures unity of effort and effective coordination of resources. Because of the enormous impact of flooding to the personal lives of the people affected by it, it is advised to enable the public to check if the organization responsible for their safety against floods are well organized, trained and have access to the necessary resources. Annual reporting is an effective tool to ensure transparency of local community flood preparedness.

2.3.3 Policy (strategic) governance and decision making

Because every country or region has its own governmental organization it is not possible to describe one governance system as best practice. In many countries the responsibility for managing the water systems with its flood defences, is in one ministry, while the responsibility for the safety of people and property is in another. Also, a system of three or more levels of government is not unusual (e.g. national, regional, local). To manage flood emergencies effectively, the different policies of these levels of governance should be aligned beforehand (and not during the emergency).

Typical responsibilities for the various stakeholder organisations are shown in Table 2.7. Figure 2.8 shows an example of how this is implemented in Belgium.

Table 2.7: Typical responsibilities for stakeholder organisations at the policy level

Stakeholder	Responsibility
Ministry of Infrastructure and water works	- Responsible for a sound water system and flood defense system, complying to national and international laws - Defining the flood protection standards - Funding the reinforcement programs on national level - Monitoring if locals stakeholders comply to the policy - Evaluating and actualizing the standards every 25 years
Ministry of Internal affairs	- Responsible for the safety and wellbeing of the people living behind the flood defenses - Responsible for protection of critical infrastructure and industry - Responsible for emergency funds in case of first aid actions to affected areas
Lead local flood authorities or Flood Risk Management Authorities	- As owner of the river systems and or flood defenses they are responsible to implement the flood protection policy. - In some cases they raise their own funds via tax (Water Boards in the Netherlands) - Via periodically assessments prove that the flood defenses meet the standards - Via duty of care have a day to day task to maintain the flood defense and water systems - Have trained and well equipped emergency response teams
Local flood defense owners	- As owner of the flood defenses they are responsible to implement the flood protection policy. - Via periodically assessments prove that the flood defenses meet the standards - Via duty of care have a day to day task to maintain the flood defense and water systems

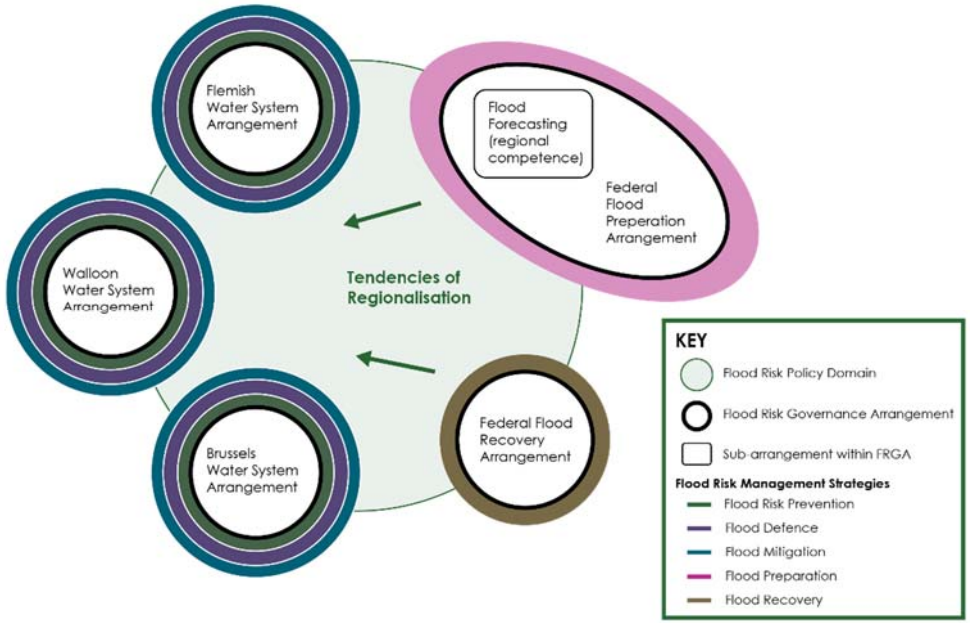

Figure 2.8 The five separate Flood Risk Governance Arrangements (FRGAs) in Belgium (after: Mees et al., 2016)

2.3.4 Planning (tactical) governance and decision making

Regional or local authorities are typically responsible for the management and operation of the flood emergency response at the regional or local level. The national (federal or state) government supports the regional/local authorities by developing the legal system for flood emergency response and the coordination between them. Typical responsibilities for various organisations are given in Table 2.8.

Table 2.8 Typical responsibilities for stakeholder organisations at the planning/tactical level

Stakeholder	Responsibility
Ministry of Infrastructure and water works	- Issuing of early warnings - Overall coordination and information-sharing in the event of flood threats at a multi-regional or national level - Deployment of limited resources (e.g. equipment), taking account of the range of national risks at the time - Close collaboration with other governmental bodies to ensure best decisions are made
Ministry of Internal affairs	- Protection or even evacuation of people and infrastructure from the affected areas - Responsible for emergency funds in case of first aid actions to affected areas
Ministry of Agricultural or rural development	- Inform farmers and habitants of rural areas for upcoming floods - In decision making, assess the economic effect of floods in agricultural areas
Ministry of Finance or Secretary of Treasury	- Establishment of emergency funds
Ministry of Defence	- Potential assistance in scenario building - Potential advice on strategies to protect the area
Regional and local flood authorities or Flood Risk Management Authorities, Drainage boards	- Establishment of emergency management plans for river systems and/or flood defences (if owner) - Maintaining up-to-date data information systems - Maintaining close collaboration with other stakeholders - Definition of scenarios (reasonable worst and reasonable best case) and preparation of action plans - Training, equipping and mobilising emergency response teams
Meteorological office	- Issuing early warnings
Local flood defence owners	- Establishment of emergency management plans for river systems and/or flood defences (if owner) - Maintaining up-to-date data information systems - Maintaining hydraulic models to predict the development of storm surges and river discharges - Maintaining historical knowledge of behaviour of water systems and flood defences under high hydraulic conditions - Maintaining close collaboration with other stakeholders - Definition of scenarios (reasonable worst and reasonable best case) and preparation of action plans - Training, equipping and mobilising emergency response teams

In situations where conflicting interests arise between the responsibilities of the organisations involved, it must be possible to escalate to a higher policy level in a timely manner. For example, an escalation to regional or national departmental level or even a national interdepartmental consultation with the Prime Minister or President as chair.

To clarify the roles and responsibilities of all actors and to promote appropriate decisions and actions without confusion, the plan should be formulated as a document.

2.3.5 Governance when implementing emergency management

If an early warning pulls the trigger that a flood emergency is likely to occur, preparations for this should start as early as possible. In some geographies and with forecast models this can be 5 days ahead, but sometimes it is less than a day. The Environment Agency (UK) has this slogan describing the general principle: “Think big (worst case scenario) act early (start as soon as possible), be visible (make the stakeholders and public aware of the hazard and that you are acting).”

This is the moment that the flood emergency plans come in to action and all stakeholders act according to their agreed roles, tasks and take their responsibilities. Typical responsibilities of various organisations for implementation are given in Table 2.9, with an example for the Netherlands in the call-out box. Public and non-professional organisations may well also offer their help (to protect their properties). But the emergency management organisations must ensure that their safety is secured and that their help is productive instead of counterproductive.

Smooth implementation is achieved not only by having a sound policy and plan in place, but also by providing regular education, training and field exercises to the stakeholders at times when there is no emergency. More details about education, training and field exercises are given in Chapter 3.

Implementing emergency management in the Netherlands

National water authority Rijkswaterstaat, as executive office of the Ministry of Infrastructure and Water Management, provides access to info of Water Management Centre Netherlands and informs regional water authorities about the situation in surrounding countries, the situation in the Netherlands and the probability of exceedance of thresholds of water levels (code yellow, orange or red). Rijkswaterstaat contacts regional water authorities about measures that should be taken, including those at a larger than regional scale.

The Water Management Centre Netherlands, gathers, processes and analyses data received from Rijkswaterstaat. They send their findings to Rijkswaterstaat and regional water authorities.

The regional water authorities make risk assessments, decide where to take measures and discusses with Rijkswaterstaat about measures that should be implemented at a larger than regional scale. They also are in close contact with the regional safety authority, municipality and Rijkswaterstaat about any measures that need to be implemented

The regional safety authorities are in close contact with the municipalities and regional water authorities about measures that should be taken. The chairman has the authority to facilitate evacuation at a regional scale (scale too large for a municipality to handle).

Table 2.9 Example of roles at the operational level

Stakeholder	Responsibility
Regional and local flood authorities or Flood Risk Management Authorities, Drainage boards	- Start actions based on the scenario process - Operate flood emergency plans - Inspect the flood defences frequently or - act immediately when a flood defence is damaged or starts to fail - Share information on the actual risks with stakeholders - Chair or be member of operational decision teams - Evaluate the situation continuously based on new meteo information, discharge models, actual situation in the field, etc. - Ensure health, safety and wellbeing of own staff and others involved in this emergency - Provide clear and up to date information - Manage communication during emergencies
Meteorological office	- Frequently update the meteorological situation and forecasting
Local flood defence owners	- Operate flood emergency plans - Inspect the flood defences frequently or - act immediately when a flood defence is damaged or starts to fail - Ensure health, safety and wellbeing of own staff and others involved in this emergency - Provide clear and up to date information
Municipalities, safety regions, fire brigade and / or police departments	- They are responsible for the protection of citizens, life stock (cattle), property and (vital) infrastructure - prepare for evacuation in case the situation leads to flooding of the area at risk
Ministry of Defence/ the army	- Ministry of Defence can assist flood defence owners to operate emergency measures. - Has trained staff and equipment (like Chinook helicopters)
Public	- Can help local flood defence owners by performing emergency measures - Can give valuable local historical information on the flood defences
Media	- A source of information to remote areas - Can help to send the right communication - Make public aware of the severity and scale of the hazard to come
Insurance companies	- Need evidence that the emergency response protected valuable areas or properties as good as possible

2.3.6 International support and coordination

Floods are devastating events that have enormous impact on people living in the flooded areas. Therefore, those trying to prevent a flood disaster will do all they can to stop water flooding vulnerable areas and to ensure a flooded area recovers afterwards. However, international help may be requested by the government of the flooded area/country in situations such as when a flood emergency

- Is very large or endures for a prolonged time;
- Has demolished or exhausted the limited resources of an organisation to fight floods (materials, equipment, knowledge or staff);
- Has not remained within national or regional borders.

The Sendai Framework for Disaster Risk Reduction 2015-2030 (Sendai Framework) provides Member States with concrete actions to protect development gains from the risk of disaster.

International cooperation is most successful when professionals working together also understand each other. This requires:

- Cooperation during the preparedness phase, since during an emergency the host organisation has little time to direct any assistance from other organisations;
- Engagement between professionals of the different organisations during the preparedness phase to ensure they understand each other immediately, in terms of both their mutual operational procedures and the language used to facilitate emergency communications;
- Formal agreements such as Memorandums of Understanding between governments, emergency response protocols, cross border agreements. These formal agreements open doors for informal contacts (license to operate). Informal arrangements include training together, sharing knowledge, contact lists (names and phone number).

Examples of institutes that can be asked to help organizing international aid

- United Nations (UNDAC) environmental dimensions of emergencies;
- United Nations Office for Disaster Risk Reduction (UNDRR) and the Sendai Framework;
- EU Civil Protection;
- NGOs such as Red Cross/Red Crescent.

2023 examples demonstrating international collaboration.

- During a flood emergency in Western Europe (2023), mobile barriers were sent to prevent overtopping (Germany-Netherlands).
- After the dam failure in the Ukraine (2023) high volume pumps were provided to drain the flooded area Ukraine-UK-Netherlands).
- During a breach of a spillway in the Netherlands in December, UK experience with rock bags and placing them with Chinook helicopters was shared on a Saturday morning via WhatsApp. This only happened because the experts knew each other, had worked together during other events and knew that the UK experience would be helpful.

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CHAPTER 3

Preparedness

Key messages:

- **Prioritize preparedness**
- **Use forecasts and scenarios**
- **Coordinate governance**
- **Foster collaboration and joint training**
- **Engage communities**

Figure 3.1: Structure of the handbook

Other places to find information on the topics of this chapter

Chapter 2: high level overview, showing where preparedness fits into the emergency cycle

Chapter 4: response phase, i.e. the subsequent quadrant of emergency cycle and how it builds on the preparedness phase

Chapter 5: causes of floods that are considered, including typical lead times

Chapter 6: an overview of the types of flood defences that are considered

Chapter 7: insight into the (organization of) communication needed for a crisis

Chapters 8 to 12: details of the process and what needs to be prepared beforehand, starting from early warning and inspections, to assessing potential failure mechanisms, to selecting emergency measures as well as sorting out the logistics and implementing the measures during an event

Chapter 13: health, safety and wellbeing aspects during the preparedness phase

Chapter 14: the role of reliability analysis in understanding how to improve preparedness

Chapter 15: working together as well as defined capacity building activities in the preparedness phase

Chapter 16: justifying the funds for the needed capacities and capabilities, focusing on the preparedness phase

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The Reader is kindly requested to take note of the Disclaimer on page ii of this handbook.

Chapter title page photograph:

A field exercise conducted in collaboration with multiple flood response organizations (courtesy: MLIT)

Key messages

- **Prioritize preparedness.** Success in flood risk management depends on being prepared. This includes building awareness, knowledge, and understanding, taking proactive actions, and updating emergency plans. High-level training is essential, even if the skills are never needed.
- **Use forecasts and scenarios.** Utilize weather, river discharge, and storm surge forecasts to plan and respond effectively. Develop trigger levels in advance to optimize response times and inform the public early.
- **Coordinate governance.** Effective flood response requires coordination among all responsible organizations. A unified plan and clear communication can prevent misunderstandings and ensure aligned responses.
- **Foster collaboration and joint training.** Joint exercises help organizations understand each other's roles and develop the skills needed to work seamlessly together during flood events.
- **Engage communities.** Involving communities enhances flood awareness and strengthens overall preparedness and resilience.

Before emergency managers, flood defence managers, responsible officials and citizens in general can activate a response to avert failure of the flood defences, they must be prepared. This preparedness requires that all concerned know what to do, when and how to do this and with what means.

Preparedness consists of a series of actions and measures taken in advance to better respond to and manage a disaster. This starts with understanding the hazards and risks involved as well as the defences that are in place. Regarding the latter, this ideally involves having up to date information regarding the condition of the flood defences.

Generally, official information is provided in the form of a warning. Warnings must be presented clearly and concisely so that the hazard and associated risks are easy to read and understand and to make sure that they serve their purpose. As stakeholders have different understandings of what a risk is, different means of communicating and presenting information are required. For example, a warning may trigger the building of a temporary flood defence or the raising of an existing flood defence. However, this action must be preceded by a timely forecast and warning of the flood, an understanding of the hazard and associated risks, and prior training on how to implement this specific action.

Warnings therefore depend on input from forecasts. Forecasts can be roughly divided into weather (rainfall, storms, change of temperature), river runoff (discharge), storm surge (water rise) and inundation forecasts (extent and water depths). An important feature of forecasts is the lead time, in other words the period between the release of a forecast and the occurrence of the predicted phenomena (hours or days). Depending on the main driver of floods forecasts may have very different lead times. This is important because the actions taken by stakeholders need to be aligned with these lead times (further details can be found in Chapter 5) and the nature of the preparedness required.

Communication of those forecasts and warnings is paramount for a successful management of preparedness. Therefore, it is important to

understand what floods are, the characteristics which make them hazardous to people and infrastructure, and their consequences.

Flood risk management now is seen to include both the emergency management of the resilience of defences and of communities. Emergency management of flood defences includes having systems in place to reinforce defences or provide temporary defences. It also includes preparation of action frameworks, including:

- Training of individuals or teams to promote the direct capacity development of flood defence personnel.
- Community engagement interventions to provide local people with important information and knowledge, including (especially for small catchments with short lead times) the need for self-evacuation.
- Incorporating local knowledge into formal decision-making.

The main objectives of this chapter are to:

- Outline what planning and preparation needs to be place and which steps need to be undertaken to achieve this (see section 3.1); this includes community engagement and awareness.
- Define and understand the hazard and risk and what this means for the flood defences (see section 3.2).
- Set out the forecasting (see section 3.3) and early warning (see section 3.4) systems that needs to be in place to be able to respond.
- Understand the flood defence systems in place and how this can result in a trigger to respond (see section 3.5).

3.1 Planning and preparation

3.1.1 Planning introduction

For effective preparation, coordination, and implementation of flood defences, a comprehensive flood defence plan should be developed by the flood defence manager and made available to the public and the core parties of the flood defence. Examples of plan development are given in Boxes 3.x and 3.y. It is essential that the plan, associated training and exercises, and actual event experience is subject to a continual improvement cycle (see further discussion in Chapter 15).

3.1.2 Capacity building and field exercises

Within the overall flood risk management plan, the flood defence manager should have a plan regarding education, training and exercises. This plan should have the objective of ensuring that all involved are prepared and able to respond appropriately and adequately during flood event. The capacity building needs to be tuned to those involved, such that they can combine this within their other responsibilities and tasks. To ensure the capacity building is adequately paced in time, a multi-year plan should be put in place, with a clear calendar of items and milestones per year. Activities, such as regional or national exercises, need to be planned well ahead in time, not only because of their larger scope, but also because they typically involve several organisations. Examples of integration of training and capacity building can be found in the case examples below. Further information on training and capacity building can be found in Chapter 15.

Capacity building through education and training

Classroom and lecture-based education is usually the first step in flood defence capacity building. The education typically highlights a brief outline and overview of flood defences, the flood defence plan, relevant policy and the legal system. Well-designed education is a valuable tool for familiarizing the flood defence team with the expected skills and responsibilities. Education is provided through lectures, seminars and tabletop exercises. This handbook is intended to be suitable as a teaching material to cover universal topics related to flood defences, but it would also be helpful to prepare other materials according to the conditions of each region, such as historical flood events and relevant national laws and regulations.

The personnel of the flood defence team are normally engaged in other jobs except during the response phase of emergency management. In

an emergency, however, they need to demonstrate skills different from those they normally engage in. So, it is critical that adequate training is provided to enable the team's personnel to develop their skills and respond effectively to the flood defence activities.

Training may be dramatically improved by having professional instructors who have excellent knowledge and experiences to provide specific guidance to the flood defence team. As it is not easy for each flood defence manager to recruit these professional instructors on their own, it is effective if a system is established to dispatch instructors to the education and training programs conducted in each region, so that these programs can be dramatically improved.

FEMA six-step process for developing and maintaining an effective emergency plan

FEMA, the Federal Emergency Management Agency for the United States of America, has developed a comprehensive six-step planning process that serves as a roadmap for developing and maintaining an effective emergency plan and which is applicable to several disaster types (FEMA, 2020). This process helps organizations identify potential hazards, assess their risks, and develop strategies for minimizing the impact of disasters. It should be noted that the comprehensive six-step planning process may also be used by communities who are interested in self-organizing for flood response. The process is also iterative, meaning that it can be revisited and updated as needed. Applying this process to the response phase might necessitate using only a subset of the six steps, or even omitting one or two, depending on the event's urgency. This flexibility ensures a rapid and appropriate response tailored to the specific situation.

Step 1: Form a Collaborative Planning Team. The team should represent a cross-section of stakeholders within the organization (or community). It should include representatives from various departments, agencies, and organizations that may be involved in emergency management or that have a vested interest in the organization's or community's safety and well-being. The team should also include individuals with expertise in various areas such as emergency management, risk assessment, planning, and communication.

Step 2: Understand the Situation. The planning team should thoroughly understand the organization's or community's flood hazard profile. This involves identifying the potential flood hazards that the organization or community is likely to encounter. It is also important to assess the organization's or community's vulnerability to these hazards, taking into account factors such as location, infrastructure, and population demographics.

Step 3: Determine Goals and Objectives. Once the hazard profile and vulnerabilities have been identified, the planning team should develop clear and measurable goals and objectives for the emergency plan. These goals should outline the desired outcomes of the plan, such as minimizing damage, protecting lives, and restoring essential services. The objectives should attempt to be specific, measurable, attainable, realistic, and timely (SMART) providing a clear roadmap for the plan's implementation.

Step 4: Development of Emergency Plan. The plan should outline the organization's or community's response strategies for each identified hazard, including roles and responsibilities, communication plans, resource allocation, and evacuation procedures. The plan should also include provisions for training, exercising, and maintaining the plan's currency. Several appendixes, such as those required to implement principles outlined in this handbook may need to be included. In addition, Standard Operating Procedures (SOPs) may be required to supplement the plan.

Step 5: Plan Preparation, Review, and Approval. This step typically involves drafting the plan in writing, incorporating feedback from the planning team and other stakeholders, and ensuring that the plan is consistent with applicable laws, regulations, and standards. The plan should then be reviewed by the respective organization's senior leadership and approved by authorized individuals. Senior leadership is essential to ensure allocation of resources for plan implementation.

Step 6: Implement and Maintain the Plan. This involves distributing the plan to all relevant personnel, conducting training exercises to familiarize staff with the plan's procedures, and regularly reviewing and updating the plan to reflect changes in hazards, risks, or organizational structures.

MLIT (Japan) model flood defence plan

MLIT, the Ministry of Land, Infrastructure, Transport and Tourism of Japan has developed a single integrated model of the flood defence plan that will help many flood defence managers throughout Japan to formulate their plans in the same format. This will help ensure that plans are formulated and updated in a timely manner by each flood defence manager and that the quality of plans does not vary across the country. This will also help to coordinate flood defence activities between different regions in the event of larger flooding, as their activities will be based on the same formatted plan. In the model flood defence plan, the following chapters are recommended for inclusion (MLIT Japan, 2021):

1) Purpose and scope of the flood defence: Relevant laws and regulations enforcing the flood defences and the types of flood events for which the flood defence is responsible are covered.

2) Core parties: Defining the core parties responsible for the flood defence and clarifying the roles and responsibilities are covered. It is critical to clarify who is responsible for decision making, to secure and count the number of personnel working directly on flood defences, and to list the supporting organisations (e.g. police, fire brigade, private sector).

3) Operation of flood defence related facilities: Identify rules and instructions for operating related facilities (e.g., water gates, pump stations, etc.) are covered.

4) Equipment: Necessary equipment list (e.g., sandbags, rope, lighting, shovels, etc.) with the amount of each and the location of the equipment stockpiles are covered.

5) Communication: Model of the communication flows and command structure in an easy-to-understand diagram are covered (see Figure 7.5 in Chapter 7 for an example of a communication structure).

6) Flood defence deployment: Multi-stage deployment rules (e.g. 1st stage: set up a team to collect and share information, 2nd stage deploy half of the flood defence team, 3rd stage: deploy entire flood defence team) based on weather forecasts and flood conditions, and the tasks for each stage are covered.

7) Capacity building: Describe the contents, frequency and timing of capacity building, as well as expected participants (see Figure 3.2) are covered.

Dispatch of flood defence instructors to capacity building sessions in Japan (MLIT Japan)

There is often a shortage of professional instructors to provide high quality education and training, which makes it difficult to pass on and acquire the knowledge and skills needed for flood defences. In Japan, The Public Interest Incorporated Association of Nationwide Disaster Prevention dispatch flood defence experts to seminars and training at the request of the organizers of education and training (Figure 3.2). The experts are registered as personnel with the association.

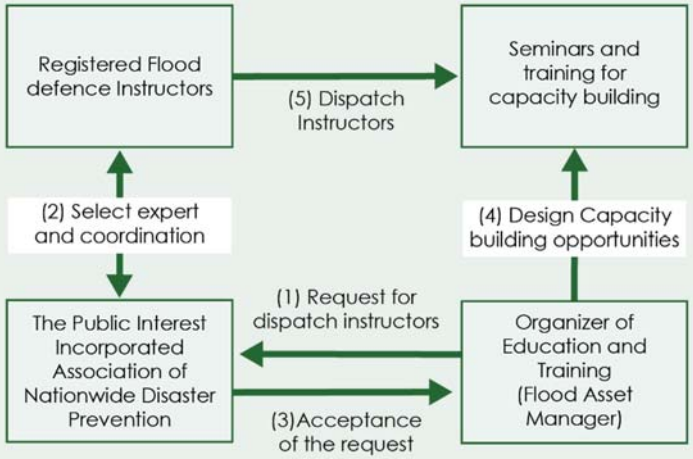


Figure 3.2: Flow from request to expert dispatch in Japan

Exercises for Emergency scenarios

Since effective flood defence requires the good cooperation of multiple stakeholders at the emergency sites, it is important to practice field exercises with the participation of all stakeholders in parallel with the capacity building of the individual personnel. Exercises are designed as field practice to simulate real scenarios, with the goal of preparing and analysing those scenarios based on the plan–do–check–act (PDCA) cycle with the involvement of all the relevant parties so that they can seamlessly transition into their roles when a real emergency occurs. Exercises may include practical contents such as mobilization of resources, communications, rescue, evacuation, and interventions.

Reporting of exercise activities is important to identify shortfalls that may exist in organizing, coordination, personnel, and equipment. A structured review or de-brief process can provide valuable feedback on the effectiveness of policies and procedures, identify areas for improvement, and give suggestions to correct deficiencies.

Full-scale river flood defence exercise event, Shinano river & Uono river, Japan (2022)

The Shinano river & Uono river flood defence exercise took place on 5 June 2022, and involved more than 1,500 players including the flood defence manager, the flood defence team, the flood defence support team, the Japanese ground self-defence force, the police department, the fire brigade, the Japanese red cross, electrical contractors, relevant government authorities, residents. Some high-level government officials including a vice-Minister of Land, Infrastructure, Transport and Tourism and Governor of Niigata Prefecture were also involved.

Each player demonstrated flood defence interventions, evacuation drills, securing lifelines, rescue drills, etc. Some hands-on experiences and exhibitions for local residents were also set up at the exercise site to promote public awareness and an understanding of flood defences (see Figures 3.3a, b and c; source: MLIT).

Figure 3.3a: Meeting of all players

Figure 3.3b: Demonstrating a flood defence intervention

Figure 3.3c: An exhibition for residents

3.1.3 Community engagement and awareness

Background

Flood risk and emergency management has traditionally been dominated by scientific and technical expertise and hierarchical top-down decision-making'. Such centralized approaches, however, may underutilize local resources and, in some cases, even increase people's vulnerabilities. Against this background, community engagement can be a promising strategy to increase flood awareness and, ultimately, community preparedness and resilience. In the context of flood risk and emergency management, the term community engagement describes a process that facilitates stakeholders working together to build community resilience to flooding by means of collaborative action and shared capacity building while building on strong relationships, mutual trust, and respect. The incorporation of local knowledge into formal decision-making can contribute to more appropriate risk and emergency management for its primary beneficiaries. Simultaneously, it can provide local people with important information and knowledge in a dynamically changing environment and increase communities' ownership of their own safety. In the following, we provide a brief introduction to community engagement for practitioners, highlighting examples of good practices.

Elements and techniques

Community engagement typically comprises establishing an understanding of the community, building and strengthening the relationship with the community, planning and preparing the process and interventions, implementing and monitoring the progress, and reviewing and evaluating the approach (Figure 3.4).

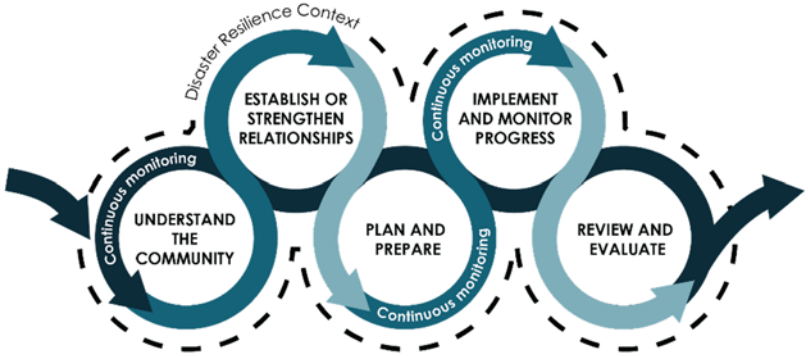


Figure 3.4: Elements of a community engagement process (after: AIDR, 2020)

Depending on the purpose, the local setting, and the time and resources available, different community engagement techniques can be used, such as workshops, information campaigns, seminars, focus groups, gamification, exercises, and storytelling. They build on various forms of interaction which - with an increasing level of community participation - include informing, consulting, involving, collaborating, and empowering. Several guidelines for practitioners are available that offer support in selecting suitable approaches (e.g., Abarquez & Murshed, 2004; ADPC, 2006; AIDR, 2020).

Example of a community engagement process in Beira, Mozambique

"Our Flood Mural" was an engagement process that was carried out for the city of Beira, Mozambique, combining interviews, workshops, and social events as part of a process to create an interactive mural painting on local flood risk. The resulting mural reflects people's experiences of past flood events, informs on the existing risk and possible risk-reducing measures in the area, and it also includes QR-codes linked to websites that show rainfall conditions for the region and describe the development process of the mural (Figure 3.5). The engagement process helped in strengthening bonds, recording and exchanging flood experiences, as well as in raising flood awareness in the community by stimulating discussions on floods during non-emergency times. Importantly, this community engagement process led to a tangible outcome – the mural – which also contributes to maintaining awareness in day-to-day life.

Figure 3.5: Flood mural painting by the local artist Hamilton Roche as part of a community engagement process to increase flood awareness in Beira, Mozambique (courtesy: Huthoff et al., 2022)

Flood awareness

A crucial component of community engagement is sustaining and enhancing flood awareness, in other words, the knowledge or consciousness of flood risk among those exposed to it. Awareness increases when a society is confronted with a hazard as well as when information and education about the risk is available with implications for appropriate actions. Awareness significantly enhances the effectiveness of flood preparedness efforts to cope with and control the negative consequences of a flood. When aware of a flood risk, people can take informed decisions and measures regarding their safety and resilience before, during, and after a flood, such as:

- Avoiding flood-prone areas.
- Constructing with materials that reduce the impact from a flood.
- Preparing an emergency kit.
- Taking an active role in the placement of sandbags.
- Evacuating when necessary while using the most effective routes.
- Documenting the damage after a flood.

Efforts to keep the memories of devastating flood events alive can be found all over the world in paintings, books, monuments, and water levels carved into buildings. However, communities tend to forget about the risks if events are infrequent, not least because of an effective flood defence system. In that case, extra efforts (e.g., regular initiatives and campaigns) may be needed to increase or maintain the level of awareness. Such efforts should not only cover awareness about the flood hazards and possible consequences for the community but also flood defence structures and the local flow paths for water if these structures are overtopped.

Lessons learned on flood awareness on the River Meuse, Netherlands

The major floods of the Meuse occurred in 1925 and 1993. In the time span of almost 70 years between these events, awareness decreased and residents along the river were not prepared for the severe inundation (Raaijmakers et al., 2008). When the area flooded again in 1995, only two years later, the local population was much better prepared, still having the memory of the 1993 event present in their minds (Raaijmakers et al., 2008). In response, various initiatives and campaigns were implemented, making information more accessible to citizens to ensure a sustained high level of awareness. Amongst these measures are:

- The website www.overstroomik.nl that allows users to see how high the water would be in the street where they live in the event of a flood and how they can prepare for different scenarios.
- The drama series "Als de dijken breken" ("When the dikes break") about a disastrous flood in the Netherlands and Belgium.

Keeping community engagement representative, fair and effective

While such community engagement interventions are nowadays recognized as a vital component of flood risk and emergency management, they can also fall short in terms of their outcomes if not well designed and implemented. This can be on the grounds of representativeness and fairness when community engagement processes focus on those local groups that already have significant knowledge and resources while those less privileged are left out (Thaler & Priest, 2014). It has also been noted that community engagement reflects a shift from government to governance, along with the sharing of disaster risk reduction responsibilities among the state, private sectors, and publics (Satizábal et al., 2022). In practice, however, the sharing of responsibilities and duties has often not been accompanied by the redistribution of power and resources. This can create a situation in which communities are blamed for inadequate flood management measures while, at the same time, their local needs are being side-lined. Chapter 15 highlights the importance of learning from such findings and, in this way, continually improving flood risk and emergency management practices.

For effective community engagement, it is crucial to place the community at the centre for planning, implementing, and evaluating the

engagement process. Each situation is unique and effective community engagement starts with understanding the context, including:

- Geographic location.
- Exposure to flooding.
- Frequency of floods.
- Community's level of awareness, its history, dynamics, strengths, and needs.

It is important to recognize that communities comprise a range of individuals whose perceptions, exposure to risks, vulnerabilities, as well as capacities and interest in risk management may vary. Vulnerabilities in the face of flooding may be related to physical and mental health and abilities, social isolation, gender, and financial security (Rudolph et al., 2022). In addition, various factors beyond awareness of the flood risk can play a role in people's behaviour during a flood. Research on people's evacuation behaviour during the summer floods of 2021 in the Netherlands (Rudolph et al., 2022), for example, shows that motivations not to evacuate were:

- A strong emotional connection to the house as the safe place that one does not give up.
- Fear of looting.
- A lack of adequate means of transportation.
- Physical barriers, such as the absence of a wheelchair ramp and portable oxygen units.

Accordingly, in community engagement processes, emphasis should be placed on including a diversity of perspectives and learning from all the 'voices' of the community with special attention to the barriers, needs, and interests of those who are most vulnerable to flood risk. This means working in partnership at every stage of the process, and balancing differences in power, information, and resources. Ultimately, community engagement requires that both the practitioners, as well as the community, commit time and effort to establishing mutual trust and to jointly solving problems for the community in the present and the future.

3.2 Understanding hazards and risk

To begin to manage floods, it is important to first understand the associated terminology. As discussed in Chapter 2, flood risk management is now the normal strategy for managing floods, although this may be complemented by resilience management (Disse et al., 2020).

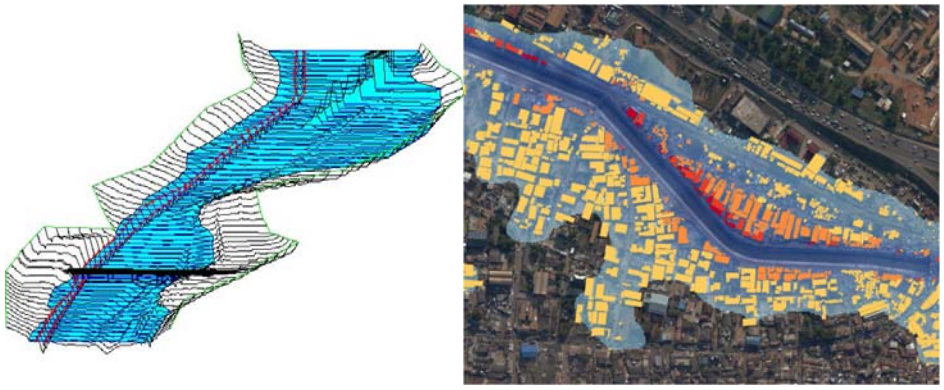
3.2.1 Hazard

In the context of environmental management, a hazard is a process, phenomenon or human activity that may cause loss of life, injury or other health impacts, property damage, social and economic disruption or environmental degradation. Hazards may be both man-made and natural. Man-made hazards are those resulting primarily from human actions, examples including industrial accidents or failures of infrastructure (including flood defences). Natural hazards, on the other hand, are the result of mainly natural processes such as hurricanes and earthquakes.

Specific hazards have an associated magnitude, which is often measured by its annual exceedance probability. Annual exceedance probability can be defined as the likelihood that an event of a particular magnitude or larger magnitude occurs in any given year. Annual exceedance probability is determined by statistical analysis of observed events. For example, extreme flood hazards (hazards with a low annual exceedance probability) have a high degree of uncertainty due to their long return periods, resulting in fewer observations.

Numerical models are often used in practice to study the adequacy of flood defence systems and consequences of a particular flood hazard should the defences be overwhelmed. (Figure 3.6). Due to the advances in computational hardware, two-dimensional (2-D) flood models can be used to simulate large areas in a relatively short amount of time. When the detail of a 2-D model is not required for a particular analysis, one-

dimensional (1-D) models can also be applied, often with even faster computation time.



(a) (b)

Figure 3.6(a): An example of the results from HEC-RAS, a 1-D flood model, from USACE HEC-RAS Hydraulic Reference Manual (2016)
Figure 3.6(b): Example results from P-DWave (Leandro et al. 2014), a 2-D flood model, with damage level marked in yellow to red scale.

3.2.2 Defence systems

Flood defences are structures designed to mitigate flooding hazards by creating separation between floods and people or assets. Defence structures can also work to retain water, thereby reducing downstream depths. These defences are generally designed to protect against hazards only up to a specific magnitude or exceedance probability. There will always be a residual risk. Examples of flood defences include levees, dams, flood walls, and tidal surge barriers (see chapter 6).

Flood defences can be subdivided into passive and active structures. A passive defence, such as a levee, is one which automatically performs its defence function when a hazard occurs. No advance warning or human input is required to operate a passive flood defence. Active flood defences, like flood walls, on the other hand, must be deployed, constructed, or operated to function properly. These flood defences require advance warning of a hazard with enough lead-time to ensure that the structure has been prepared.

As already explained in Chapter 2, flood defences experience hazards as threats, either to the defences being overtopped or to them failing or being breached. The reliability of flood defences is an estimation of their survival or, conversely, their probability of failure. To assess the reliability of a defence structure, failure mechanisms must be identified and studied to identify their likelihood, as well as the uncertainty associated with their estimation. For more information about dominant failure mechanisms and fragility curves, please see chapter 9.

3.2.3 Consequences

When a flooding hazard occurs and is not adequately mitigated by defences, the (adverse) consequences can be defined as the effects on people and objects resulting from the event. For any adverse consequences to occur, objects and assets must be located where they have exposure to the hazard, and they must also be vulnerable to the damaging mechanisms of the hazard.

- Exposure can be defined as the location of objects or people such that they could be adversely affected by a hazard event.
- Vulnerability is the propensity of a person or object to be adversely affected or damaged as the result of a hazard event.

These two attributes determine the severity of flooding consequences. When the consequences of a hazard are so severe that they exceed the ability of a community or region to cope, requiring external aid to respond and recover, a disaster is said to have occurred.

The consequences or damages due to flooding can be classified into direct and indirect damages:

- Direct damages are those caused by the physical effects of a hazard. For example, damages due to the flood depth, duration or velocity can be described as direct damages.

- Indirect damages are those resulting from the flood, separate from the physical effects. These damages can be less tangible and more difficult to estimate. Examples of indirect damages are the economic effects resulting from business interruptions or mental-health impacts due to the environmental stressors caused by a flooding event.

3.2.4 Risk

Risk is the expected consequence of a hazard with a specific exceedance probability. Therefore, the risk for a particular hazard event is (see Figure 3.7) the product of the exceedance probability of the hazard (including the contribution of the probability of failure of any defences) and the damages or consequences (including social, environmental or economic) which occur due to the exposure and vulnerability of assets.

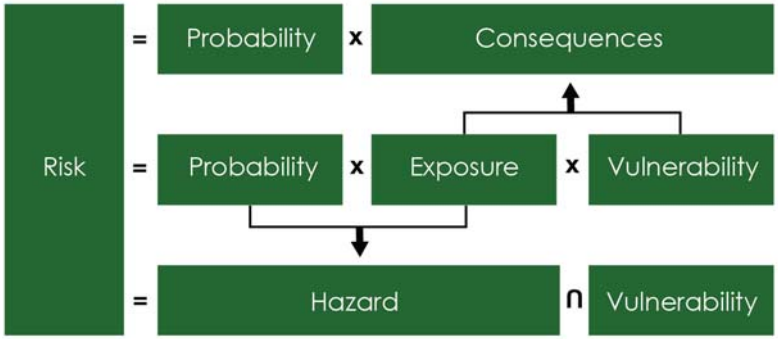


Figure 3.7: Components of risk and their relationship (source: Klijn et al., 2015, Disse et al., 2020)

Flood risk management involves the assessment of the total risk, or the risk for all flood magnitudes. The total risk is then the integral of the damages with respect to exceedance probability.

$$R = \int_0^1 D \cdot dP_e$$

As discussed in Chapter 2, flood risk management works using a portfolio of measures to reduce the effects of the hazard directly or lessen the consequences of the hazard.

Reductions of the effects of the hazard can be accomplished using:

- Water retention structures.
- Flood defences (see section 3.2.2 and chapter 6).
- Conveyance systems.
- Improved natural infiltration.
- Early warning systems (see section 3.4).

Emergency management of flood defences should be seen as an integral part of such an approach.

Management of the consequences due to flooding focuses on the exposure and vulnerability of people and assets within the floodplain. For example, exposure can be reduced by relocation of valuable objects outside the floodplain or prevention of encroachment into the floodplain. Vulnerability can be reduced, for example, by improving the water resistance of exposed buildings.

Risk assessments are performed during the preparedness phase to identify and reduce the risks associated with a hazard ahead of its occurrence. Identified risks are then communicated to the necessary stakeholders (for more information about risk communication, see chapter 7). As an event approaches, strategies implemented for risk reduction are put to the test, and the management focus shifts to monitoring, issuance of warnings, and reacting to any failures.

3.2.5 Resilience

Resilience is a concept which focusses on the ability to respond to and resist the impacts of a flood, and to recover in a timely manner while making necessary adaptations. Whereas risk management typically deals with the concrete aspects of flood management like monetary damages,

using the concept of resilience helps to focus on the more organizational and social aspects of flood management.

Resilience is closely related to systems reliability. However, rather than always seeking to maintain the current status-quo, a management strategy based on resilience seeks to make adaptations to the system. Resilient systems continue functioning despite a hazard by adapting to the changes. Managing for resilience means viewing flooding events as opportunities to adapt. When a flood occurs and a component of infrastructure is damaged, the goal should not only be to quickly repair the component, but perhaps to improve the infrastructure so that it is more reliable in future floods. This is only possible when plans for improvement are made in advance of damages. During the response phase there is no time for making planning decisions.

Resilience can also be used to manage flood defences. In this context, there is a focus on various indicators like robustness, redundancy and recoverability of the defence structure itself:

- Robustness in flood defence systems refers to the performance of the structures during events which exceed the nominal design water level. In these cases, a robust system may attempt to retain the additional water due to strategic over-design or will allow overtopping in a controlled manner. This controlled overtopping would occur first in predetermined areas identified for minimal damage and should not lead to erosion or breaching of the levee.
- Redundancy refers to the inclusion of additional mitigation strategies in combination with a flood defence system, with the goal of adding support in the case of a failure.
- Recoverability is measured by the ability to repair or reinstate a damaged flood defence in the case of damage, as well as the removal of flood water which may have caused inundation during the period of damage.

3.3 Flood hazard forecast components

Flood forecasts are necessary to prepare for an impending flood event and to issue appropriate warnings. Forecasts are predictions of future conditions. Forecasts usually run continuously all year round. They are mostly computer-based and rely on real-time measurements. In some cases, these future conditions are considered threatening, and warnings are issued so that stakeholders can prepare to take action. The simplest way to implement warnings is through a warning scale (see discussion and examples in Chapter 2). The warning scale is often translated into a severity colour code with a text attribute that ranges from none, to low, to moderate, to major threat. The severity level is selected based on trigger points, each corresponding to a colour code.

Preparedness and warnings are based on different types of forecasts:

- Weather or meteorological forecasts often predict the amount of precipitation (mm or inches) or the intensity of precipitation (mm/h or ft/h) or in wind direction and intensity of storms (Beaufort, m/s, miles/hour) The longer the forecast, the less accurate it is. According to the National Oceanic and Atmospheric Administration (NOAA), the accuracy of a 7-day forecast in the United States is 80%, while it drops to 50% for a 10-day forecast.
- River discharge or hydrological forecasts predict river discharges (m3/s or ft3/s) and water levels (m or ft). In this case, accuracy can be higher for medium to small catchments, ranging from 90% within the first few hours to 75% after 12 hours.
- Flood forecasts predict water depths, wave heights, storm surges (m or ft) and the extent of inundation (m2 or ft2) during a flood event. The accuracy in this case depends not only on the lead time (the length of time between the issuance of a forecast and the occurrence of event) but also on the range of predicted water

depths. In any case, both river and flood predictions depend on the existence of actual meteorological forecasts.

In general, forecasts are provided not only with different lead times (as already mentioned), but also with very different grid resolutions (needed to capture appropriately the physics involved).

- Weather forecasts are usually at the order of tens of kilometres. This is because of their complexity and the need to cover very large areas. They are computationally expensive.
- River discharge forecasts are on the order of hundreds of meters. Their complexity is low.
- Flood forecasts are usually given at the order of a few meters. The latter is a necessary requirement to build the complexity of the urban tissue (e.g., roads and buildings) and hence these forecasts may be computationally expensive.

Due to the know-how and resources required, not all forecast components are available worldwide. Furthermore, differences can even occur within a country, depending on how far the available services extend. The following sections describe four possible components of a forecast system, namely weather, river discharges, storm surges, and flood inundation forecasts

3.3.1 Weather forecasts

Weather forecasts are based on complex numerical models of the atmosphere. Such numerical models require the use of super-computer facilities. Some examples are the Global Forecast System (GFS), the North American Mesoscale model (NAM), the European Centre for Medium-Range Weather Forecasts (ECMWF) and the United Kingdom's Meteorology Office (UKMET). These models require accurate initial conditions to run properly. Hence, data assimilation is required. Data assimilation aims to provide the best possible initial conditions of the atmosphere and earth's surface (e.g., oceans) using observations. As such a forecast is not only a function of numerical modelling but also ground observations. Numerical models need to account for the dynamics of the atmosphere and its physical processes (e.g., cloud formation) and marine and land processes. Because the atmosphere is chaotic, there cannot be a perfect forecast. To account for these uncertainties, ensemble models are used. Ensemble models enable a probabilistic forecast to be conducted, rather than a deterministic or single model forecast. Ensemble models are a patch of models which share a starting point. but have small perturbations in parameters at the start of each model run. The combination of ensemble predictions has an associated uncertainty. As such, the forecast skill (how good it is), decreases as on moving into the future, because the results of each model run of the ensemble will start to diverge more and more from one another.

Weather forecasts are produced at national scale and worldwide, but with different spatial scales, lead times and durations, depending on the provider and geo-location. Also, national weather services may make use of one or multiple numerical models described earlier. Often, weather forecasts include several products such as precipitation, temperature, sky cover, and pressure patterns, among others. For example, precipitation can be forecast in terms of cumulative rainfall-water-depth per unit area (mm), or it can be given in terms of the intensity of precipitation, in this case rainfall-water-depth per unit time (mm/h). Box 3.5 provides an example of a weather forecast.

Weather forecasting by the German weather service, Deutscher Wetterdienst (DWD)

The German weather service, DWD, worked together with the Max-Planck-Institute for Meteorology in Hamburg to develop the ICON-Modell. ICON is a global model with a horizontal resolution of 13 km. For regional forecasts, DWD uses the COSMO-DE with a horizontal resolution of 2.8 km. For the very near-future DWD issues Nowcasts. Nowcasts are based on numerical modelling but may blend with other methods from image analysis, radar or satellite data, among others. These are intended for the next 0 to 2 hours

(see Figure 3.8). For longer forecasts, numerical weather predictions of up to 10 or 15 days are possible.

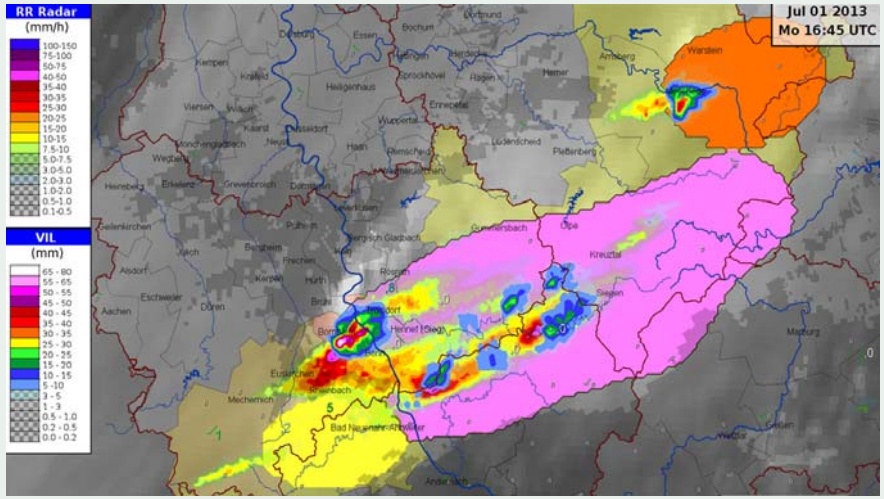


Figure 3.8: Nowcasting of rainfall for the next 60 minutes. Color scale of severity (source: Wetter und Klima - Deutscher Wetterdienst - NowCastMIX (dwd.de))

3.3.2 River discharge forecasts

River discharge predictions (which includes both river flooding and flash-floods) are traditionally based on conceptual hydrological or simplified hydrodynamic models. Such models are often called rainfall-runoff models because they establish a relationship between precipitation and overland and groundwater runoff. Examples include LARSIM (used in Germany), the HBV model (used in Scandinavia), HEC-HMS or HEC-RAS (used in North America), and LISFLOOD (used at the Joint Research Centre of the European Commission (JRC)). Alternatively, artificial intelligence is increasingly being used in research, suggesting that it will eventually be used in national services. Unlike weather forecasting, supercomputers are not required to predict discharges. As with weather forecasting, data assimilation is required, not only to provide initial conditions for the models, but also for model validation and calibration. Indeed, data assimilation does not only include observations, but also the weather forecasts already described. Precipitation is the most important factor for runoff forecasting. As with the weather forecasts, uncertainty is also taken into account in the forecasts through the use of ensemble models. In this case, the uncertainty includes additional sources. The uncertainty arises not only from the observations, but also from the precipitation forecasts, the model structure and the uncertainty of the runoff model parameters. Therefore, it is expected that the predictive accuracy decreases with lead time. It is therefore important to have the model regularly updated by experts so that changes (e.g. topography or land use) can be taken into account if necessary.

River forecasts exist at various spatial levels (e.g., state, national, continental and global). The information includes flood discharges along major rivers with associated return periods or exceedance probabilities and flood warning messages, usually together with some information on the severity of the discharge. Flood discharges are given as volume per unit time (m^3/s or ft^3/s). In addition, the water depth can also be specified. In this case, the transfer can be made via stage-discharge curves at specific gauge points or directly approximated by the forecast model outside the gauge locations. The return period (years) is an estimated average period between the occurrence of events. The exceedance probability is the probability that a certain value will be exceeded in the future in any given year. Therefore, the exceedance probability is equal to the inverse of the return period (see also section 3.2.1 on hazards).

River flood forecast by the European Copernicus Emergency Management Service CEMS

The Global Flood Awareness System (GloFAS) is a component of the European Copernicus Emergency Management Service CEMS. In GloFAS,

the hydrological rainfall-runoff model computes a complete water balance in a 6-hour or daily time step for all 5 km grid cells of the entire area. GloFAS is driven by the European Centre for Medium-Range Weather Forecasts (ECMWF) NWP model, called the Integrated Forecasting System (IFS). Uncertainty is passed on through the 51 ensemble forecasts (ECMWF ENS) (see Fig. 3.11).

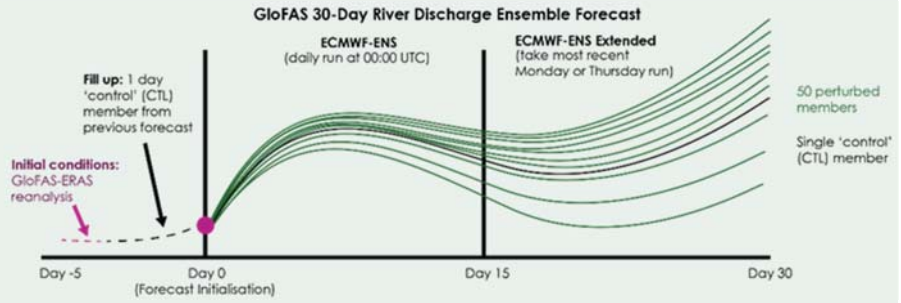


Figure 3.9: Example of GloFAS (Global Flood Awareness System) hydrological forecasting system (source: HESS - Daily ensemble river discharge reforecasts and real-time forecasts from the operational Global Flood Awareness System (copernicus.org))

3.3.3 Storm surge forecasts in coastal areas

Coastal flood forecasting is a combination of storm surge forecasting and astronomical information about tidal levels. If the high tide coincides with a storm surge, the flood impact can be large.

Tidal levels can be predicted in advance, as they depend solely on the relative position of the Sun, the Moon and the Earth.

Storm surges are weather dependent and therefore can only be predicted a few days ahead. For example, the Met Office (UK) issues coastal flood forecasts for 5 days, while NOAA makes forecasts for 6 days. The surge is predicted with global models such as the NEMO model ("Nucleus for European Modelling of the Ocean") used by the Met Office. Such models require inputs of real time data, such as wind speed and direction.

Because the probability of flood defences being overtopped is also dependent on the prevailing wave conditions at the coast, weather buoys also collect wave information as inputs to the global models to predict offshore wave conditions. Nearshore wind and wave conditions are then predicted from offshore conditions using high-resolution "local models" (Met Office) or Nearshore Wave Predictions (NOAA).

3.3.4 Flood inundation forecasts

Flood inundation forecasts exist mostly at the local level in the research stage and are not as widespread as the forecasting approaches discussed in the previous sections. This is partly driven by the computational costs of physically based models, which require a very fine grid to be considered useful. Experience of both flood managers and local citizens in relating river discharge or storm surge forecasts to actual flood conditions on the ground.

However, there are two categories of methods which are able to provide predictions of inundation flood depths:

- The use of a database of maps of inundation levels during modelled or recorded river discharge or storm surge events of various magnitudes (return periods). In this method, a similar flood event is searched for in the database based on the incoming conditions, and the most similar event is output.
- The use of artificial intelligence systems (see for example Figure 3.10), in which the system is trained to predict the outcome, again based on the forecast input. FloodHub, recently developed by Google, seems very promising to provide (partial) global flood forecasts, although information is not yet available on testing and validation of the approach.

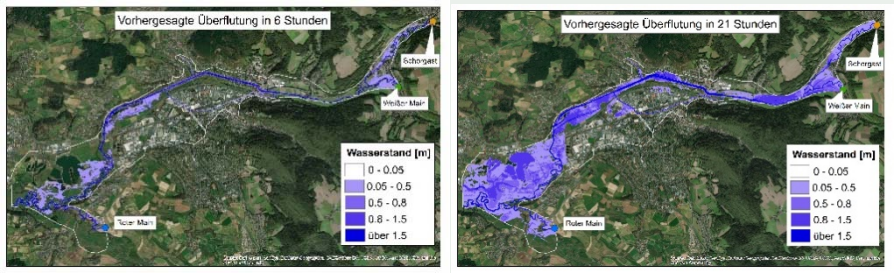


Figure 3.10: Flood inundation forecasting, including extent and water depths (source: Schmid and Leandro (2023) KI basierte „multi-timestep" Überflutungsvorhersage von fluvialen Ereignissen, KWD Workshop, Essen)

3.4 Early warning systems

While forecasts run continuously, warnings are activated and issued only when triggers (e.g. rainfall, wind, rate of change of water levels or river discharge) are expected to exceed a safety threshold for a given time. The information must be concise, easy to read and timely in order to be effective and for this reason event classification is often used (see discussion in Chapter 2). In addition, the warnings are user-specific and a warning for flood defence safety will be very different from one intended for a community.

- Warnings about the safety of a structure will be designed to focus on situations when a specific numerical safety threshold is exceeded.
- For communities with their diversity, warnings using a general severity scale are more appropriate, with warning information focused on how to respond. It is also likely that governmental and non-governmental organizations will receive separate more detailed warnings in order to be prepared and take appropriate action.

Early warning systems are an important part of flood risk management. They are aimed at providing warning messages about an impending threat to minimize its impact. They comprise a chain of sensors, event detection ('forecasting') and decision support systems for the early warning of natural disasters. They exist on a regional, national, continental or global scale.

The way that early warning messages are sent varies widely around the world and some examples of early warning systems are given below. Messages can range from simple sirens or tones to signs, texts and pictures over national or local media. The use of telecommunication tools such as mobile phones allows for the development of specialized apps that provide comprehensive and targeted issuance of alerts. Each means of communication working together can play an important role, since individuals may not have access to a specific means. Lack of access may arise from factors such as social deprivation, power outages, failure of media or mobile phones. Thus, basic but robust alternatives such as sirens, loudspeakers or door to door visit by flood wardens can still provide important means of early warning.

European Flood Awareness System (EFAS)

EFAS provides a Europe-wide probabilistic early warning system for flood risks and hazards. The information includes flood discharges along the main rivers with the corresponding return periods as well as flood reports. This information is disseminated to the relevant national and regional authorities (see list of partners here4), complementing existing national warning systems. EFAS also provides information to the Emergency Response Coordination Centre (ERCC) to coordinate the joint efforts of all EU Member States and other participating states.

Flood warning system implemented in Bangladesh

The Wireless Sensor Network (WSN) consists of a ground-based network of sensors (Figure 3.11a) that detect water levels upstream and automatically warning people via sirens (Figure 3.11b) and text messages on mobile phones.

a

b

Figure 3.11a: ground base water sensor Figure 3.11b: siren system (source: SERVIR's Wireless Sensor Network (WSN) Flash Flood Early Warning System Deployed in Bangladesh > SERVIR > SERVIR | Global | Articles (servirglobal.net))

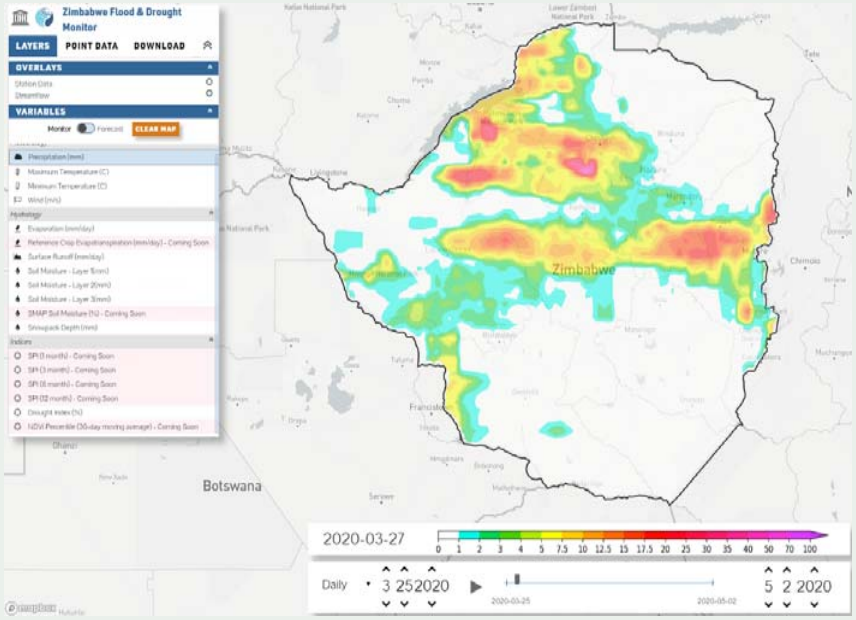


Figure 3.12. Zimbabwe Flood and Drought Monitor (source: A New Flood and Drought Monitoring System for Mozambique and Zimbabwe – ICIWaRM)

Early warning systems in Mozambique and Zimbabwe

The Mozambique and Zimbabwe Flood and Drought Monitor are two nationwide experimental systems for early warning of flooding (Figure 3.12). The forecasting system is based on ground, satellite and modelled data sets. These are combined to provide hydrological conditions in near real time and produce flood forecasts of up to seven days. The system includes the HBV hydrological forecast model (5km resolution) and the ECMWF to forecast the climate.

Examples of smart phone warning apps implemented in Germany

Nowadays, specific warning apps for mobile phones or smart phones are becoming increasingly popular as a means to reach citizens and inform them about an impending threat.

The German Federal Office of Civil Protection and Disaster Assistance (BBK) has developed the app NINA and the Fraunhofer Institute has developed the app Katwarn. Both apps provide information to German citizens about various types of risks, including flooding, which are specific to where the person is located via

the GPS signal. However, low uptake of these technologies and patchy development are drawbacks of these technologies.

In response to the severe floods in Europe in July 2021, Cell Broadcast was developed and tested in Germany. Cell Broadcast is a mobile phone service that sends warnings directly to mobile phones or smartphones. In Germany, it is probably the warning channel that can reach the most people directly.

3.5 Flood defence information and performance

3.5.1 Design and observed performance

Flood defences (see Chapter 6) can be man-made structures like earthen embankments, flood walls, dams, locks or storm surge barriers. However, natural systems like dunes and higher grounds also give protection against flooding. They all have one thing in common: they must be managed (with inspection, maintenance, permitting, operation, etc.) in such a way that they will maintain the required level of protection given the consequences of flooding of the hinterland. Such management comprises of:

- **Regular inspections (and subsequent maintenance).** Due to the daily exposure to all kinds of elements (e.g. precipitation, land use, animal activities, unwanted growth of vegetation, wear of critical parts, construction activities, illegal activities), flood defences can be damaged or deteriorate. Whilst all kinds of anomalies can arise within a few days, it is not feasible nor necessary to inspect the flood defences every day. A more appropriate approach is to have a combination of the following:
  - Regular inspections at a frequency appropriate to the robustness of the critical elements and the impact of any failure. For example, one inspection may be scheduled shortly before the flood or storm seasons starts (with enough time to repair critical anomalies) and one shortly after (to check whether any damages have occurred).
  - Situation-dependent inspections before, during or after a severe event e.g. a storm or drought that provide insights into deviations that have occurred since the most recent previous inspection. Even if such inspections only cover part of the defence (e.g. the outer slope of a flood embankment), they provide insights and allows for repairs to damages that may later be invisible or difficult to reach.
- **Periodic full assessments.** Sound flood defence management depends on understanding the total water system that the flood defences are part of. Ideally, the original design approach (data, methods and results) remains available so that if the boundary conditions change (e.g. altering hydraulic conditions due to climate change, land subsidence) the validity of the design can be checked at a regular frequency (e.g. 10 to 15 years).

Flood defence checks in the Netherlands

In the Netherlands, a flood defence manager is obliged to carry out a full assessment every 12 years. The Minister of Infrastructure and Water Management provides the assessment instruments and gives the hydraulic conditions taking account of the expected impact of climate change over the coming 12 years. Flood defence managers are also obliged to report every year whether their management process is delivering flood defences that continues to meet the required standard.

3.5.2 Flood defence records

It is good management practice to have an asset information system/database that is used to collect, store, process and analyse the information that is required to manage the flood defences over their lifecycle (Institute of Asset Management, 2015). There is a wide variety of asset information systems, even within flood risk management, typically

with a mapping element. They are normally software applications, but paper-based systems still exist. In addition to location and alignment, they may include any of the following:

- Type of the flood defence.
- Owner.
- Details that relate to the defence's performance, such as:
  - Standard of protection, condition.
  - Geometry/design dimensions (sometimes with references to further technical details such as drawings).
  - Geotechnical information.
- Real-time status of temporary measures (e.g. whether all openings are closed off).
- Information about performance requirements, performance history, receptors at risk.

Some asset information systems have added functionality for analysis and to support management decisions, for example workflow modules, visualisers and performance assessment tools (see discussion of fragility curves in Section 3.5.4 below). A typical challenge for asset management systems, relevant for emergency management, is multiple ownerships within a network of defences; ideally, all these flood defences should be captured in a single asset information system.

Emergency management requires flood defence information, for example, likelihood of breach at forecast loading level and associated flood extent and receptors at risk. The circumstances of emergency management also pose requirements on the format of the asset information system: usability in a high urgency environment, and sometimes by rostered staff who do not use the system regularly. Finally, the decisions based on the information are different during emergencies: whether and where to evacuate; whether and how to prevent impending breaches; how to repair breaches. For this, other systems may need to be consulted, e.g. databases with flood hazard maps or even with flood scenarios.

In some cases, it may be worthwhile developing a dedicated flood defence information system (or module within the general system) for use in emergencies, but in practice the general system is typically used. It is important to practice use of the system in emergency exercises and address lessons learned. The advantage of using a system that is used in daily management is that people are familiar with it and it is better kept up to date. (Such a general system should therefore include information that might highlight areas of the defence

system more prone to an approaching flood - either because they are being rehabilitated or are due for an upgrade.) It is also easier to move from the preparedness to the response phase. However, it is useful to build in a filter so that abnormalities that are not important during a flood can be made temporarily invisible.

Flood defence information systems are in many cases made available as open data; more detailed information is then made available for professionals within an organisation's system.

Example flood defence information systems in Europe

England: the Environment Agency's Asset Information Management System (AIMS): https://environment.data.gov.uk/asset-management/index.html

The Netherlands: the 'Waterveiligheidsportaal' (water safety portal) developed by a partnership of the relevant authorities: https://waterveiligheidsportaal.nl/#!/home

National Levee Database for the United States of America

The National Levee Database (NLD) provides a comprehensive inventory that captures information about all known levee systems across the United

States. As a dynamic and searchable resource, it provides critical data for flood risk assessment and levee management activities. Currently, the NLD includes details for approximately 7,000 flood defence systems that meet specific criteria. The available information encompasses aspects such as location, operation and maintenance organizations, levee length, height, and the year of construction. For more detailed data or to explore specific flood defence, users can access the NLD through its online interface at https://levees.sec.usace.army.mil/about/about-the-data/

3.5.3 Failure mechanisms

A key to good management of flood defences is to ensure a sound understanding of the flood defence system. Part of this is understanding what type of loads the defences are subject to and subsequently how these may fail. This section elaborates the way to understand failure mechanisms and the subsequent section how to quantify the probability failure using fragility curves.

Flood defences can breach due to several causes, known as failure mechanisms, which often act in combination or sequence. Breach generally occurs because of a sequence of events, where the increase of the hydraulic load on the defences during the emergency is generally the starting point. To subsequently arrive at a response to avoid any mechanism or at least slow it down, it is essential that flood defence managers understand their defences and the associated mechanisms.

For earthen embankments a distinction is made between hydraulic, geohydraulic and geostatic failure mechanisms. For non-earthen water retaining structures, various other failure mechanisms can be distinguished, including untimely closure or re-opening of gates in structures, excessive leakage or flow through a structure, block sliding of a structure, and structural failure in general. For a more detailed overview of the various types of failure mechanisms see Chapter 9.

For the flood defence manager to arrive at the understanding of potential failure mechanisms, various options are available which can be used singly or in combination:

- Review of existing information, including design and as-built drawings and documents, which can provide insight into which mechanisms are relevant and / or dominant.
- Identification of failure mechanisms using expert judgements based on visual inspections as well as obtaining details that have been obtained during historic events that have led to breaches. This is often the most effective and low-cost option.
- Additional investigations to understand the ground conditions and the properties of the materials of the flood defences, followed by modelling to assess under which conditions a defence may breach and why (i.e. which failure mechanism). Such investigations and calculations are often relatively costly.

3.5.4 Fragility curves

Once the applicable failure mechanisms of a flood defence are known, the flood defence manager can progress to creating fragility curves. A fragility curve shows the variation in the failure probability of a stretch of flood defence as a function of a dominant load parameter such as the water level. The fragility curve differs from one failure mechanism to another and depends on the strength properties of the flood defence. The resulting conditional probabilities of failure described by fragility curves can be used in combination with the known water levels (or other hydraulic conditions) to indicate the safety status during an event.

To prepare for emergency situations, the fragility curves need to be derived (Wojciechowska et al., 2015; Kolen et al., 2019). Having identified the potential failure mechanisms, some kind of limit state equation, model or other expert understanding of each mechanism is required, together with a list of the main parameters which affect the mechanism. With this information and understanding, the derivation of full fragility curves and

subsequent visualisation of failure probabilities can be undertaken. However, this may be data intensive and hence potentially costly. Often a more pragmatic approach is taken if data availability is limited, including any combination of the following:

- Derivation of fragility curves based on either expert judgement or on simplification of the failure mechanisms and use of available data.
- Identification of weak spots based on (a combination of) expert judgement, flood risk analyses and field observations.

Knowledge about the history of a flood defence, prior flood risk assessments or characteristics of a flood defence (such as subsoil, hydraulic load and revetments) can be used by a (local) flood risk expert to validate the fragility curves or to determine the dominant failure mechanisms if fragility curves are not present.

The greater the uncertainty regarding the strength, the less steep the fragility curve, as fragility is then low. Figure 3.13 illustrates example fragility curves for an earthen embankment for different failure mechanisms as well as for all mechanisms combined. Uplift and piping generally are uncertain due to uncertainties in the subsoil (and hence a mild slope of the fragility curves), while failure due to overtopping and overflow is generally more predictable (and hence a steep slope). More details on fragility curves and the derivation of fragility curves are detailed in Chapter 9. The failure mechanism with the highest conditional probability of failure is the dominant failure mechanism.

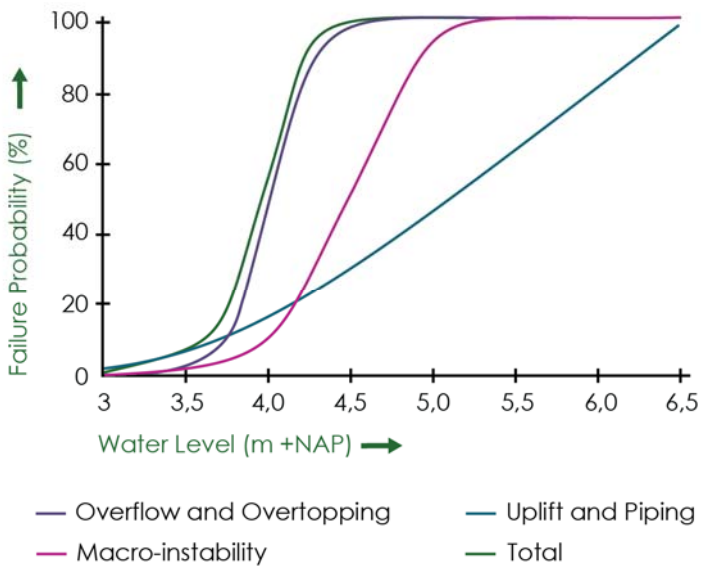


Figure 3.13: Example of fragility curves for earthen flood defences (source: ENW, 2017)

Information regarding failure mechanisms and fragility curves for each section of a defence can be documented in flood defence management databases (see section 3.5.2). The defence sections can also be hyperlinked to a document describing the emergency or management measures for this section for each occurring failure mechanism.

3.5.5 Surveillance systems

Further to the monitoring of hydrological and hydraulic conditions that are used in early warning systems, surveillance systems are available that provide information on the stability and functionality of the flood defences. These systems can be installed and used to continuously monitor the conditions. Once the dominant failure mechanisms of the flood defences are known (see section 3.5.3), the choice and design of

such systems can be tuned to specific needs (e.g. monitor conditions relevant to a particular failure mechanism). Further to aiding emergency management, such sensors can also provide valuable information that can be used for general maintenance of the flood defence systems (monitoring behaviour in time).

Information regarding pore pressures, leakages, movement and settlement can be obtained from both sensors in the flood defences as well as remote sensor (e.g. in satellites, drones). These can be used to provide real-time information on the actual conditions but can also be used – in combination with forecasts of lead times - to forecast stability conditions in an upcoming event. This then can help define the most appropriate response.

Examples of surveillance systems include:

- Pore pressure sensors.
- Electric Resistance Technology (ERT).
- Fibre optic cables.
- Aerial surveillance systems to aid inspections during a flood event (see details in Chapter 8 and 11).
- Imagery provided by satellites, including from:
  - InSAR (Interferometric synthetic aperture radar) to observe deformations.
  - Multispectral imaging, e.g. to observe drought (stress).
- Sensor technologies mounted in drone systems, often offering most of the common sensor technologies available from satellites, but with higher resolution and more flexibility in a single drone system.

In the following two examples are given for local monitoring systems and remote sensing (drone) surveillance systems.

Local surveillance of Vistula River, Cracow, Poland

A Multi Points Thermal Sensor (MPointS) local monitoring system (see Figure 3.14) was installed in 2017 on the existing levee of Vistula River close to Cracow and verified during high water levels in 2019 (Radzicki et al., 2021). The system is used for thermal-active leaks detection and seepage velocity determination and for estimation of the risk of erosion occurrence. (In the near future, two further systems are to be installed.)

The system is installed along a levee in sensitive zones of the levee along its landside toe and in its subsoil. These sensitive zones are identified in advance by other methods, for example based on observed leaks during a high water level or based on a high permeability zone detected with geophysical methods, etc. The monitoring collects information about the intensity and development of leaks and the risk of internal erosion

The near-term goal for the surveillance is to monitor all known sensitive zones of levee system during even minor higher water levels in the river in order to be able to execute precise and optimised repairs before the occurrence of critical flooding. In the further future, the MPointS systems will also serve levee monitoring during flooding, aiming to identify areas requiring immediate reinforcement.

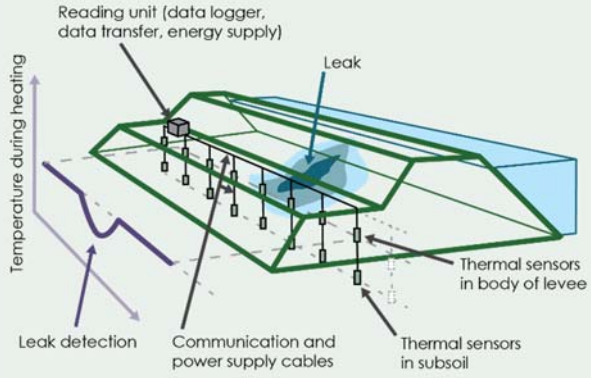


Figure 3.14: Schema of local MpointS system for quasi-linear thermal monitoring of leaks (source: Radzicki et al., 2021)

Use of drone-mounted infrared sensors for dikes in the Netherlands

Drones can now be mounted with thermal infrared remote sensing to observe leakage in the hinterland of a dike, even in a ditch. In the winter of 2022, a pilot took place to test a detection algorithm for using infrared images (collected by a drone) to detect possible leakages. The pilot was held in the Willemspolder (The Netherlands), an area between a summer dike and winter dike along the Waal River with known leakage issues.

Leakage can be an indicator for internal erosion or piping if soil material is carried along with the leakage flow. The leakage can be detected by the thermal difference between the leaking (groundwater) flow and its surroundings. This is a limitation of this technique, but for many countries in temperate or cold climates it is useful since the storm and high water period is in the winter period. The groundwater temperature is around 10 degrees Celsius year around, while the outside temperature in the winter is lower than 10 degrees Celsius.

Such drones can be operated by dike inspectors with no or limited experience and/or qualifications. With this proven technique a large area along a dike can be inspected for leakages during a highwaters in limited time, while inspectors can use the visual view for other inspection aspects. The challenge is to interpret the detected higher temperature (hotspots) in the area and to determine if this is a possible leakage. (Not every hotspot is a leakage, since presence of animals, human or vehicles also shows a hotspot on an infrared image.) Detection algorithms are desirable to support the dike inspectors interpreting the images, a challenge which applies to all imagery techniques. Data processing is needed to make the imagery valuable and efficient.

Figure 3.15 illustrates the infrared image of a part of the pilot area, the detected leakage by the detection algorithm and earlier reported leakage spots by the dike inspectors. Although the pilot was a limited test of a detection algorithm, it shows that remote sensing techniques can be made valuable and efficient in combination with data processing techniques.

Figure 3.15: A plan view of a part of the pilot area. Red patterns indicate relative warmer spots. Black outline shapes are the leakage spots by the detection algorithm. Red diamonds are the earlier reported locations nearby leakage spots by the dike inspectors.

3.5.6 Triggers of potential failure of flood defences

Early warning systems for failure in technical flood protection systems, such as levee failures, are designed to provide timely and accurate information to stakeholders, allowing them to take necessary actions before a disaster occurs. They are based on the concept of threshold triggers. These triggers are used to identify potential problems and to activate the necessary response plans to prevent failure. Possible triggers for failures of flood defences include rising water levels, saturation time, ground subsidence, erosion of levee material, and animal burrows (Table 3.1). Once the trigger is activated, the system provides information on the level of risk and the expected time to failure. The stakeholders can then

take appropriate action to prevent or mitigate the consequences of failure. The threshold values used for the triggers are determined based on the defence's design, the local environment, and the potential consequences of failure. (All this information should ideally be available in the asset management system, as discussed in section 3.5.2). The threshold values must be set at a level that allows for adequate warning time while minimizing the risk of false alarms. Threshold values for defence failures can be determined through a combination of field monitoring, modelling, and analysis of historical data (CIRIA, 2013).

Table 3.1: Potential triggers that can be used to identify risk (adapted from: Schueller, 2022)

Trigger thresholds	Detailed Information
Hydrological values	– Water level at reference gauging stations, – Telemetry networks that exist across river and levee systems and on the coast, – Discharge at a reference gauging station, – Evolution/forecast (rising, stagnant, falling) of water level/discharge at a reference point (e.g. gauge), – Flooding of critical areas/embankments, – Rate of water level rise, – Design water level of the flood control system, – High soil moisture or low soil moisture (drought).
Alarm level/ Warning levels/ Message levels	– Alarm and notification levels from disaster management plans, – Flood Alerts and Flood Warnings, – Evacuation levels (pre-alarm, evacuation alarm, control phase).
Meteorological values and warnings	– Trigger thresholds of the respective weather service for weather warnings, – Measured area precipitation with predefined location-specific thresholds, – Warning messages / forecasts of the weather service and from warning apps.
Technical failure/ condition of technical equipment	– Threshold of unplanned failures (e.g. erosion, cracks, animal impacts, pump failure – Threshold of planned failures (Reaching the design water level), – Time until the system fails, – Webcam observation on flood protection system, – Recorded damage patterns at flood protection structure.
Observation on-site / monitoring	– Visual findings/observations, – Results of monitoring, – Photos, – Webcam observations, – Other monitoring equipment, – Ground movement equipment, radar to measure material movement/loss
Other	– Historical knowledge of floods in the past and how the flood defence system reacted, – Workload of those responsible for flood protection, – Utilization rate of own material resources, – Filling status and operational status of polders, or flood storage reservoirs, – Emergency call via call number recognition (leads to display of location), – Rescue access shortly before damming, – Linked indicators with multiple triggering thresholds (AND/OR marking), – Necessary set-up time for the execution of measures.

Trigger levels or conditions can be defined using fragility curves (see Section 3.5.4). These conditions are those discharges, water levels, wind/wave conditions at which breaching is potentially going to occur. For visualisation purposes, the failure probability can be linked to an alarm category and/or colour code. Figure 3.16 shows an example of a map in which the alarm categories are presented for all levee sections. The figure

illustrates the actual conditional probability of failure in an area (<1%) and increases to 15% in 24hours and 45% in 48 hours. At the bottom of the figure, the total length of levees in an alarm class over 24 hours are given (157.6 km in class safe (green), 1.0 km in class yellow (warning), 0.9 km in class orange (danger) and 2.8 in class red (critical) (Kolen et al., 2019).

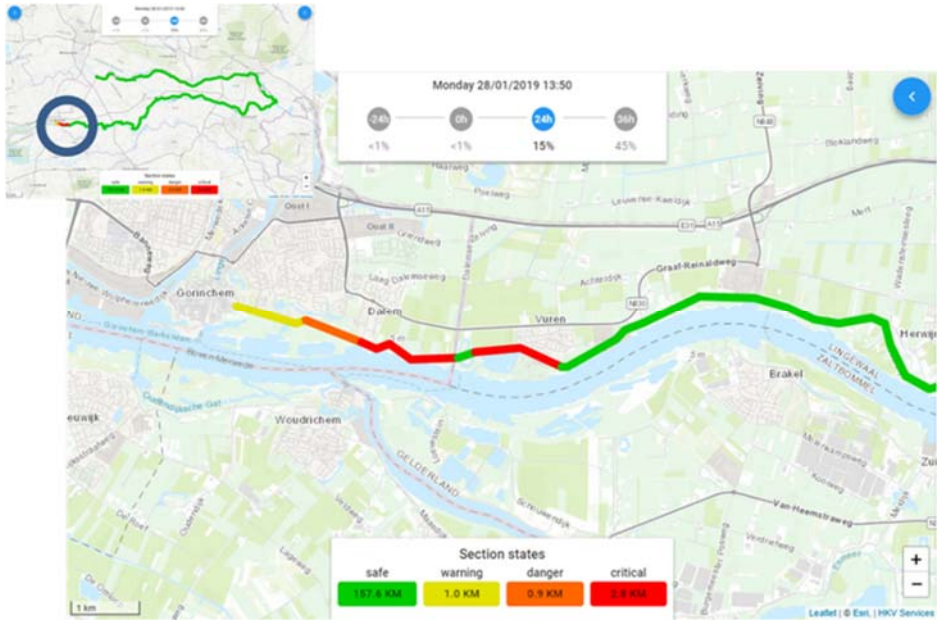


Figure 3.16: Interactive map of dike ring area 43 (The Netherlands)

It is important to note that not all systems, or the entire lengths of systems are necessarily monitored in real time. Reports may be received for issues in places that are not actively monitored or known to be at risk. Additionally, it is important that relevant organisations have considered generic approaches to responding to different causes of damage depending upon the flood defence type and are able to implement repairs to the typical associated risks (CIRIA, 2013).

3.5.7 Time-dependent failure

Time dependency of failure is an important aspect of emergency management. The moment of onset of flooding is uncertain and failure mechanism specific. For example, geotechnical failure mechanisms like piping and instability generally have a strong time-dependent character. They are likely to be initiated in conditions lower than the design standard but are associated with relatively longer durations between initiation of the mechanism and subsequent breach. By contrast, the maximum discharge due to overtopping or overflow generally occurs during the peak of an event and is associated with a relatively shorter duration between initiation and breach.

Time dependency in failure mechanisms makes the available time after the decision-making phase until the start of failure uncertain (Barendregt et al. 2005). The available time for action therefore cannot be determined in advance. This also means that this window of time to execute measures cannot be documented and guaranteed in advance.

Although statistics are used for the design of flood defences and multiple causes of failure can occur, limited experiences with such extreme events are available. This lack of experience is reflected in the uncertainty of the window of time available for evacuation or emergency measures, arising from:

- Variability and unpredictability (e.g. of the weather system or flooding).
- Imperfect knowledge of a system (e.g., forecasts, flood defences).
- Ambiguity (e.g. linguistic problems).

Thresholds to initiate emergency management structures or implement other measures are in most cases defined relative to measured or forecast water levels. Emergency planning (and exercises as well) is based on these thresholds and expected windows of available time. This will only result in an optimal decision when these uncertainties (such as time dependency of failure mechanisms) do not influence the decision.

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CHAPTER 4

Response

Key messages:

- **Think big – Act early – Be visible**
- **Assess – Analyse – Act**
- **Understand each emergency as unique**
- **Make prompt and clear decisions**
- **Communicate clearly**

Figure 4.1: Structure of the handbook

Other places to find information on the topics of this chapter

Chapter 2: high level overview, showing where response fits into the emergency cycle

Chapter 3: preparedness phase, i.e. the previous quadrant of emergency cycle and how it provides a basis for the response phase

Chapter 5: causes of floods that are considered, including typical lead times

Chapter 6: an overview of the types of flood defences that are considered

Chapter 7: insight into the (organization of) communication needed during a crisis

Chapters 8 to 12: details of the process and what needs to be done in the response phase, starting from early warning and inspections, to assessing potential failure mechanisms, to selecting emergency measures as well as sorting out the logistics and implementing the measures during an event

Chapter 13: health, safety and wellbeing aspects during the response phase

Chapter 14: the role of reliability analysis in understanding how to improve response

Chapter 15: working together as well as defined capacity building activities in the response phase

Chapter 16: justifying the funds for the needed capacities and capabilities, focusing on the response phase

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Note:

The Reader is kindly requested to take note of the Disclaimer on page ii of this handbook.

Chapter title page photograph:

RAF Chinook placing big bags (Wainfleet, England) (Crown Copyright 2019)

Key messages:

- **Think big – Act early – Be visible.** The preparedness attained in advance is the core support framework for the event as it evolves. To prepare for the worst it is necessary to develop reasonable worst-case scenarios, to take actions before it is too late and to promote to the public and government what is being done.
- **Assess – Analyse – Act.** Undertaking real time **A**ssessment of the situations, **A**nalysis of the risks, and **A**ctions (AAA) is key for organisations to mitigate the risks of flood structure failures and the impact on the public and on their own operations and reputation.
- **Understand each emergency as unique**. Flood defence emergency organisations should be ready to understand the threats to the defences posed by the unique characteristics of the event, that the situation will change and that multiple events may follow. Organisations therefore should be prepared to reassess and adjust.
- **Make prompt and clear decisions**. Timely and clear decision making during an emergency is required to best mitigate risk. Delays increase the risk of an adverse condition occurring and reduce the effectiveness of response. Prompt decision-making can be informed by fragility curves for the flood defences which give the probability of defence failure for any given forecast water level/condition.
- **Communicate clearly**. Common and unambiguous communications should be delivered through standardised protocols. Clearly communicating when the end of an event has occurred will improve the ability to capture post-event data that can inform future improvements and lessons identified.
- **Collaborate within and between organisations**. Local flood defence emergency managers rarely have the full resources necessary to manage large or multiple events immediately available. Collaboration within and between organisations at both regional national and international level should be considered and organised, with prior agreements and protocols for joint working.

The response phase is a complex and non-linear process that requires careful planning, execution and evaluation. It includes early warning, initiation, inspections, evaluation of failure mechanisms (see Chapter 9), response strategies, and post-response activities. It is a vital process for organisations to identify, assess, and respond to emergencies that can impact their operations, reputation, and/or impact the public. Chapter 3 provided insights into the planning and preparedness for emergencies. This chapter covers the deployment of these planned and prepared activities and strategies during emergencies, aiming to provide a comprehensive understanding of the process and its key components. By following the processes outlined in this chapter, adopting appropriate responses when trigger thresholds are exceeded, and managing the inherent risk of setbacks or reoccurrences during an emergency, organisations can minimize negative impacts, ensure timely and robust recovery and foster long-term resilience.

In the realm of emergency management, the response phase involves the immediate actions taken to address the emergency. Response reduces the potential for adverse consequences by:

- Protecting property.
- Ensuring the safety of affected individuals.
- Saving lives.

The response phase requires careful consideration of the Health, Safety and Wellbeing (HSW) aspects (see Chapter 13) of activities undertaken by organisations and personnel (office and field based) before, during and after an emergency.

As the response phase finishes, it unfolds into the recovery process, which focuses on rebuilding communities to their pre-disaster state or better. The time period for this transition varies, influenced by the rate of recession of floodwaters within catchments, and includes

rebuilding infrastructure, providing essential services, and supporting affected individuals in resuming their normal lives.

The subsequent sections of this chapter address:

- Section 4.1 – the response phase process.
- Section 4.2 – inspections and assessments.
- Section 4.3 – collaboration and response coordination.
- Section 4.4 – immediate post response activities.
- Section 4.5 – types of emergencies.

4.1 Response phase process

Successful emergency management requires timely decision-making and actions. Delays increase the risk of an adverse condition occurring and reduce the effectiveness of response. A well-defined event initiation and decision-making process should enable the emergency manager to make prompt decisions to respond. The process requires the definition of trigger levels and initiation mechanisms during the preparedness phase, as discussed in Chapter 3.

It is important to 'Think big and act early' - that is to say, consider the reasonable worst-case scenario that could occur and plan for this scenario by taking early action. Decisions will almost always be based on partial and imperfect information and there can be multiple conflicting decisions to be made. However, delays in decision-making to await improved information may adversely impact the ability to mitigate potential consequences and may compound the risks that organisations are seeking to mitigate. The initiation and decision-making process therefore needs to adopt an appropriate level of precaution by leaning toward response and action rather than seeking/awaiting perfect information. It is better to plan for the reasonable worst-case scenario and then demobilise resource and equipment if it is not needed, rather than not to have mobilised the equipment early enough and then need it.

Organisations should consider in advance how they will deal with conflicting priorities. This includes identifying what the level of authority required in each organisation to make a particular decision and the process by which conflicting choices can be resolved. Decisions should be evidence-based rather than relying on instinct or perception of risk. Such evidence should include understanding of the infrastructure at risk in the area landward of the flood defences.

4.1.1 Process overview

The initiation of any emergency response process is likely to involve exceedance of pre-defined thresholds and triggers (see section 3.5.6 and discussion in Chapter 3). Pre-defined initiation triggers remove the pressure of trying to assess relative risks during an emerging event and therefore expedite decision making and activation of the emergency management process. These triggers are a core outcome of the preparedness process of event management.

From initiation, management of the overall process should be well defined and clear to avoid delays or misdirection of resource with corresponding adverse impacts on the ability to mitigate risk. The preparedness process should include development of a clear event management process that covers both escalation and de-escalation during the event (see Chapter 2).

Event classification is an important step in the process as it helps reduce the potential for misalignment of processes within and between organisations. If all organisations involved share the same classification system, the risk of misalignment is minimised and supports better decision making. Once an event has been classified, useful comparison for planning the response can be made with any relevant scenario(s) (see Chapter 2) which have been evaluated as part of preparedness. Events will typically be reclassified as they

evolve. Reclassification (see Chapter 2) helps to ensure the right decision is made regarding the ongoing response and the resource required to protect the public.

As well as event classification, the understanding of failure mechanisms for the flood defences and the use of trigger levels (see Chapter 3) is an important part of an effective response process as these tools will aid the understanding of the threats to the defences and influence the selection of response strategies.

It is important to recognise that during an event, new triggers and/or threats can arise or reoccur. An effective response process should therefore be agile and adaptable to respond to evolving circumstances and thus differs significantly from procedures during normal (i.e. non-emergency) periods.

The procedures for emergency management should unambiguously outline the conclusion of the response phase, enabling a seamless transition to the recovery phase, noting that recovery efforts may commence prior to the conclusion of the response. Any ambiguity in marking the termination of the emergency should be avoided since it undermines the capacity to gather valuable post-event insights (see Section 4.4), which are instrumental in driving future enhancements and in the extraction of key learnings (refer to Chapter 15).

4.1.2 Process for decision-making

The core aspect of effective decision-making is identifying the nature of the decision required. Challenging yourself on what decision is needed develops and drives the process toward making that decision. A typical decision process for emergency management has the following sequence.

1. Identify the decision to be made.
2. Gather relevant information. This includes information on:
   - the expected flood event (time, duration, peak water levels).
   - historical floods and emergency measures that have been taken, noting which measures were successful or not.
3. Consider the information available.
4. Consider alternative courses of action, including various combinations of inspections and interventions.
5. Identify which emergency measures can be implemented considering the available information and the available time, knowledge and materials.
6. Make the decision and take action, while monitoring the effectiveness of the selected information and the updated flood event information.
7. Review and evaluate the decision & associated outcomes with regard to detection, installation and operation of the emergency measure. Prepare documentation with actions that should lead to better preparedness for the next emergency.

Decision making needs to be evidence-based and timely to support the best chance of mitigating risks. Marewski and Gigerenzer (2012), suggest three types of rules that support rapid decision making:

- Search rule: specifies in what direction the information search extends within the search space.
- Stopping rule: specifies when the information search is stopped.
- Decision rule: specifies how the final decision is made (see also discussion in Chapter 3).

Forecasts, triggers, scenarios and classification systems prepared in advance provide direction for the first rule and define limits for the second rule. Collectively these support and expediate points 2 to 4 in the decision-making process.

Before a well-informed decision can be made, a process of sense-making is required. If the situation does not make sense, poor (or no) decisions may arise, so applying a sense test will help the decision

maker when pressure exists to take rapid action. The processes and actions required to make sense of a situation are covered under chapters 7 to 12; they augment the expertise of the decision maker and further support points 3 and 4 in the decision-making sequence given above.

How the final decision is made, and by whom is discussed as part of governance in chapter 2.

4.1.3 Managing multiple events

Emergency events seldom follow a simple sequential pathway. Multiple loops and incidents may well occur within the overall event or emergency. Emergency preparedness planning must recognise the real possibility of multiple incidents both within the duration of the primary emergency and potentially for some time after the primary event has passed. During management of an event, it is often necessary to modify responses and change priorities as the situation evolves.

Flood preparedness is typically unable to quantify and plan for the many scenarios that involve combinations of events. When multiple or cascade events occur, it is highly likely that those involved in managing the flood will be tired, and the resilience of local communities reduced, following the primary event. Coupled with the presence of interim or fresh repairs, secondary events can often bring a disproportionate level of risk to those being protected by the flood defence system. The depth of capacity and experience in emergency management organisations will be instrumental in how multiple or combination events (see section 4.5) are eventually mitigated and how the health, safety and wellbeing of responders is managed (see chapter 13). This applies whether the responsible organisation is working alone or in collaboration with others (see Section 4.3)

4.2 Inspections and assessments

Inspections, which are discussed in Chapter 8, play a critical role in monitoring and assessing the situation, providing valuable and timely information for decision-making. They help to identify potential risks and guide response efforts. Countries and organizations around the world use various types of inspections, and each will have differing objectives for those inspections (CIRIA, 2013). In this chapter, the focus is on inspections immediately before, during, or after emergencies.

The inspections and assessments should supplement existing information in the database of any asset management system (see Chapter 3). They should ideally be recorded in a formal report that can be used either to pass information to decision-makers (i.e. to inform emergency maintenance or repair options) or after the emergency to inform required improvements to assets or plans. It can also help the organisations to justify their actions in legal situations (CIRIA, 2013), e.g. public enquiries. Inspections should be carried out at the appropriate level of responsibility or experience in organisations, e.g. flood defence managers, flood fighting teams, emergency services, and local governments.

4.2.1 Inspection preparation for flood events

Before any inspection, the flood infrastructure owner/manager should be notified so they can plan the inspection. Poor preparation for inspections will inhibit their effectiveness and risks potential issues being overlooked. The arrangements may include (CIRIA, 2013):

- Mowing grass.

- Securing operations personnel and equipment (ladder, safety harnesses, lifts, traffic control.
- Special vehicles to traverse the flood embankment etc).
- Identification of areas where special arrangements may be necessary to gain access (confined spaces, gated/locked areas and/or high water).

the emergency may require inspections to be carried out at short notice; this must however never be a reason for those undertaking the inspections to not adhere to the arrangements above and health, safety and wellbeing precautions.

4.2.2 Undertaking inspections before/during/after emergencies

The International Levee Handbook (CIRIA, 2013) lists near event inspection, in-flood inspection and post-flood inspection regarding flood event. The guidance provided in the International Levee Handbook (CIRIA, 2013) is equally applicable to all types of flood defence, recognizing of course each piece of infrastructure is likely to have some specific aspects:

- Near event inspections should be performed shortly before an approaching loading event to verify that all parts are in order.
- In-flood inspections (see chapter 8), performed in person or by drone, satellite or aircraft while the flood defences are loaded, are extremely valuable in:
    - Validating existing knowledge from flood risk assessments or experts.
    - Identifying weak or susceptible areas that could lead to a potential failure, some of which may not have been anticipated given existing knowledge.
    - Improving knowledge on dominant failure mechanisms (see Chapter 9).
    - Planning and implementing emergency repairs.
    - Initiating population evacuation.
- Post-flood inspections are crucial in observing any damage and changes that may have occurred and evaluating the ability of a flood defence to withstand a future loading event. Changes in the river or coast (sediment etc.) during the flood can impact hydraulic conditions and hence design standards even when no "damage" has occurred. This type of inspection is also used to validate, verify and to add to information collected during the flood event and to update any asset management database (see Chapter 3). This could lead to subsequent plans for:
    - Urgent and future work to maintain or improve the flood defences.
    - Improving ongoing knowledge growth (see Chapter 15).

If resources are a limiting factor, inspections should be focussed on those lengths of flood defence that pose the highest risk (CIRIA, 2013), such as those:

- For urban areas or critical infrastructure.
- With a history of poor performance or with known weak or susceptible materials.

Typical responsibilities of those undertaking flood infrastructure inspection are detailed in chapter 5 of the International Levee Handbook (CIRIA, 2013).

Chapter 13 covers the Health Safety and Wellbeing (HSW) aspects of site visits, including during an incident when weather conditions could be very severe. Personnel must adhere to their organisation's specific HSW requirements for undertaking tasks and wearing the appropriate Personal Protective Equipment whilst undertaking a given activity or task – this applies to both field and office-based activities.

4.2.3 Use of fragility curves to assess flood defences in an emergency

As explained in Chapter 3, use of information on the probability of failure conditional on load (e.g. water level) derived from fragility curves is a common tool in emergency management. It is helpful as it describes the varying probability of failure during the event and thus of the safety status of the flood defence in emergency management. To permit fragility curves to be used in this way, measured or forecast water levels are required (Kolen et al., 2013). The forecast local water level is then combined with the fragility curve of the flood embankment (cross) section to derive the conditional probability of failure.

Also as in Chapter 3, the derived failure probability can be linked to an alarm category and/or colour code to give emergency managers an overview of weak spot in their flood defence system and the resulting impact on flood risk in various zones within that system (see Figure 4.2) For each zone, alarm categories can be used to visualize the conditional risk (Kolen et al., 2013). This helps to prioritize and focus inspections of flood defences or the execution of flood mitigation measures. Where fragility curves are not present, such an overview can be established based on local knowledge or prior flood risk assessments.

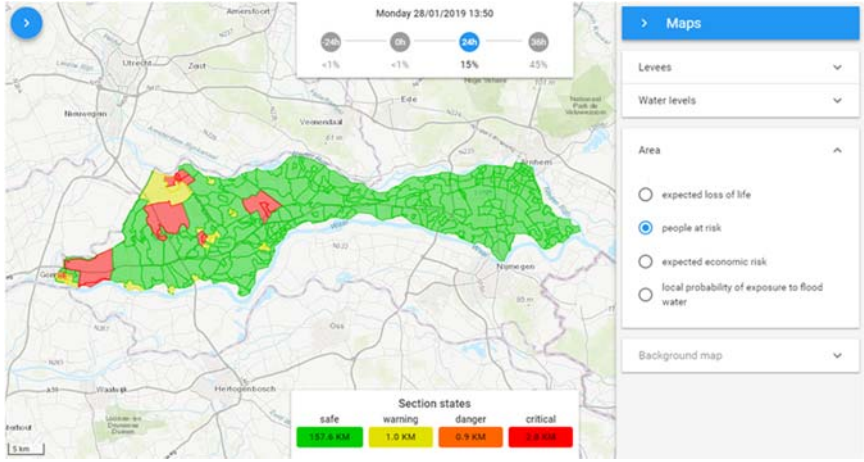

Figure 4.2: Interactive map of conditional risk within a defended area (source: Kolen et al. (2013))

4.3 Collaboration and response coordination

Usually, an organisation's own assets are first to be used in the response and to assist other units in neighbouring areas or other administrative regions. Indeed, organisations that span a larger area should offer mutual aid within their organisations i.e. support from an area that is not affected to an area that is affected. Different roles and responsibilities among related organisations, residents, companies, the military and others will dictate the role they play in response, whether on their own or in collaboration with other agencies. In this, military and civil defence assets are considered a last resort (United Nations, 2007).

When not an organisation's own resources are insufficient, capacities from other organizations and/or international disaster relief may be required in the form of collaboration (mutual aid) between multiple

departments and between different organisations. Whilst an organization's primary focus will be their own operational response, collaboration across organizations or nations is something that should be considered as early as possible in the run up to an incident or during spontaneous incident response. This is particularly important in the case of international assistance, which can necessarily take longer to arrange and is worth considering in advance of an incident.

Response coordination can be defined as (United Nations, 2013):

> "*intentional actions to harmonize individual responses to maximize impact and achieve synergy – a situation where the overall effect is greater than the sum of the parts*".

Response activities require solid coordination and thus procedures for coordination of response activities should be agreed and planned during the preparedness phase (see Chapter 3). The departments and organisations in the region affected by the emergency may require direct help with that emergency or support to deliver their other functions while their own personnel are engaged with the emergency. During the preparedness phase, initiation and decision processes should therefore be aligned between all organisations involved in emergency management. As discussed in chapter 15, training and exercising together can significantly enhance the ability to mitigate misunderstanding and inefficiency. Such alignment, training and exercising together will reduce the risk of misunderstanding between organisations arising from variations between their response frameworks.

Mobilisation of response resources in England by the Environment Agency

The Environment Agency in England developed an approach to ensure timely mobilisation of mutual aid resources from areas outside the emergency, preparing an appropriate plan as the emergency develops. This enables quicker activation of additional support and aids transition into recovery.

The approach was adopted in December 2015 to respond to the flooding in Cumbria and Lancashire Area. where all other Environment Agency Areas in England sent support in the form of personnel and equipment, as illustrated in Figure 4.3.

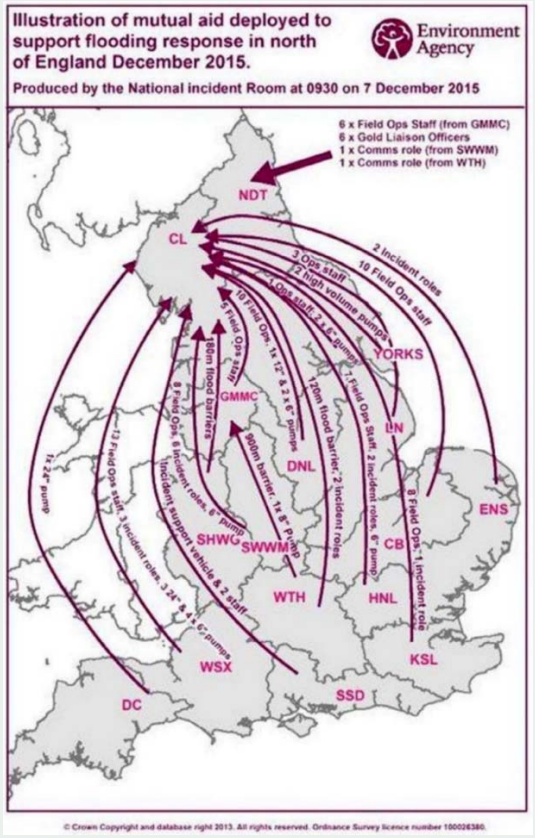

Figure 4.3: Illustration of Environment Agency resource (personnel and equipment) sent to support the response to the Cumbria and Lancashire flooding on December 2015

Environment Agency free Flood Warning Service in England

This service provides warning to the public and partners when flooding is expected: https://www.gov.uk/sign-up-for-flood-warnings. When issuing these Flood Warning, professional partners are alerted and multi-agency working is undertaken to support communities.

By reducing the pressure personnel face during an emergency, mutual aid can also have a significant positive impact on the health, safety and wellbeing of personnel (see chapter 13 for more information).

Mutual aid within or between organisations can be beneficial when only one region is impacted but its value decreases the larger the physical size of the emergency and the number of personnel involved in its management. In such situations, international support could be considered as discussed in Chapter 15.

There are two types of assistance that may be delivered through a coordinated collaborative effort:

- Single disciplinary assistance (e.g. fire brigade assisting fire brigade, thus within their own discipline).
- Multidisciplinary assistance (e.g. police assisting the fire brigade, both contributing their specialist discipline, making it multi-disciplinary).

Examples of responsibilities that require a multidisciplinary approach, necessitating close cooperation and coordination across disciplines include:

- **Warning and informing.**
  - Warning and informing of communities and businesses.
  - Evacuation instructions and assistance.
  - Management of evacuation shelters.
  - Patrol.
  - Traffic control.
  - Provision of information and advice to local administrators via hotlines from flood management administrators.
  - Communication with politicians.
- **Operational response.**
  - Flood damage mitigation activities in local areas.
  - Flood water drainage by pump stations.
  - Dispatch of drainage pump trucks and lighting vehicles from flood risk management administrator.
  - Emergency work to prevent (progress of) flood embankment breach.
  - Sharing of equipment that can assist in mitigating failure during the emergency.
  - Closure of breached flood embankment.

Example

By way of an example of coordinated response, civil resilience in the UK is underpinned by the Civil Contingencies Act (2004) and civil response partners operate under the Joint Emergency Services Interoperability Programme (JESIP, 2023) which ensures an effective response with the aim of 'working together, saving lives, reducing harm' (see Figure 4.4). JESIP sets out the principles for joint working - Co-locate, Communicate, Co-ordinate, Jointly Understand Risk, Shared Situational Awareness - and a consistent reporting framework for use by partners. See the JESIP website: https://www.jesip.org.uk/

When responding to a flood incident in 2019 in Lincolnshire, England, where we had a major breach of a flood embankment, the Environment Agency collocated with Local Resilience Forum partners in the County Emergency Centre so that we were face to face and best able to manage the Strategic and Tactical level responses to the incident. The Strategic Coordinating Group was Chaired by the police and used the

Joint Decision Model to assess the risks and develop the strategic objectives for the response and to make effective decisions together. See Join Decision Model: https://www.jesip.org.uk/joint-doctrine/the-joint-decision-model-jdm/

More details on the JESIP response structure are given in Chapter 7.

Figure 4.4: Cycle of activities during the response phase of emergency management

Coordination should rely heavily on "Sense making", "Meaning making", and "Decision making" (Boin et al., 2013):

- **Sense making:** Those involved in leading/coordinating a response should have common ***sense*** of what the situation is, and when responsible for sending responders to the scene of a disaster a clear understanding of the situation they are sending personnel into is critical. For example, knowing your personnel will be going to a flooded area means an organisation should assume that there will be the possibility of hazardous materials in the water as flood water is usually a mix of substances, such as sewage, damaged household oil tanks and chemicals from industrial processes.
- **Meaning Making:** Once a sense of an incident is understood, it is important to consider what is relevant to the operation - thought must be given to the ***meaning*** of the situation (compiled in the sense making stage). For example, if operational sense is that there is likely to be chemicals in the flood water, this may mean response operations in the area needs to be stopped or does consideration of how to mitigate the risks in a responsible way mean the task can continue, e.g. using the proper personal protective equipment or taking other precautionary actions.
- **Decision making:** Lead administrators of emergency management will ultimately need to ***decide*** what to do or what not to do. They will need to assess the risks and use on site risk assessments to determine whether it is safe for personnel to proceed with the tasks they are being asked to undertake.

4.4 Immediate post-response activities

Post-response activities should involve a seamless transition from immediate response measures to recovery and long-term management actions. Some core activities crucial for effective management in the post-response phase include the following:

- **Post-Incident Data Collection**
  Prompt data collection should begin rapidly after an incident to capture vital information on flood extents and other details for

modelling and adjusting trigger levels. This work can in turn inform future warning and informing of the public.

- **Initiation of Recovery Phase**
  Alongside ongoing response efforts, the planning and initiation of recovery measures should commence concurrently, necessitating a coordinated multi-agency response, led by either the flood authority or the local authority. This work may include:
  - Planning for the emergency/permanent repair of defences.
  - additional work engaging with communities which have been impacted.
  - developing future flood risk management schemes to mitigate the impacts of future flooding.
- **Management of Evacuations and Accommodation**
  The handling of evacuees is a critical component of this phase, including the provision of temporary housing and planning regarding the timing for their safe return. Caution is advised when considering the return of evacuees, as flooded properties often require extensive time for restoration - this can mean emergency evacuation shelters need to be maintained for longer or evacuees found alternative accommodation.
- **Waste Management**
  Addressing the waste generated by the event and subsequent cleanup efforts presents a significant challenge for local authorities and should not be underestimated. Large volumes of additional waste can be generated as homes and businesses repair the damage from the incident, particularly in cases of fluvial or tidal incidents involving the management of large amounts of sediment and debris, which is also potentially contaminated.
- **Learning from Events**
  Debriefing after an emergency is important as it enables lessons to be identified that can improve future response. The analysis and integration of experiences from major flood events are crucial to optimize operational response systems and training. Chapter 13 gives more information on debriefing and learning lessons.

Post-incident data collection is critical for a variety of reasons, including understanding the full extent of flooding, updating flood models, future emergency access and egress planning and the development of future flood risk management schemes to mitigate future risk. However, there is currently a lack of standardized procedures and criteria, hindering comprehensive post event analysis. Establishing uniform international criteria would be crucial for accurate assessment of operational flood protection measures and damage.

To enhance operational post-flood response, operational experience should be integrated into education and training programs. While professional training exists for fire departments and relief organisations, the timely integration of operational flood protection experience requires further optimization. State administrations and other stakeholders involved in operational flood protection would benefit from targeted training programs to improve their capabilities. Simultaneously, conducting parallel event follow-up and deficit analysis during the reconstruction phase is recommended. By implementing these measures, a comprehensive operational flood response can be achieved, ensuring effective post-incident management, continuous improvement, and enhanced flood preparedness (see also Chapter 15) (Schueller & Juepner, 2021; Schueller, 2022).

4.5 Types of emergencies

The following types of emergencies may need to be managed:

Multiple events. Storm events may arise in a manner that the resulting flood event itself induces multiple individual incidents. A storm that moves up a catchment can first induce significant stress to defence systems in the lower catchment through storm surges, localised flooding, rainfall induced saturation and weakening of flood embankments and structures. The flood event itself may then occur sometime later as the wider catchment responds to the storm, placing high stresses on defences that are already partially compromised. Similarly, catchments with areas of snow can frequently experience secondary flood events as warm storm events, already responsible for downstream flooding, melt snowpacks.

Cascading defence failures. Flood defences typically consist of many components that operate both as discrete elements and within a coordinated system. As a flood event progresses down a catchment system, defence systems progressively get placed under stress increasing risk of component failure through many different failure mechanisms (see Chapter 9 for details). Performance failure of defence structures can add secondary stressors on downstream defences that may already have reduced resilience having been subjected to the main event. This can lead to a cascade emergency event potentially more significant than the unmitigated flood might have induced, as failure induced peaks combine and amplify the risk and potential consequences.

Delayed failures. While failure of a specific defence element may be most probable at or near the peak of an event, failure can occur at any time. For example, peak saturation of earthen embankment structures often occurs sometime after the flood peak has passed, increasing the risk of failure mechanisms arising from saturation. Similarly, flood detention dams are typically designed to absorb the peak of the flood and therefore, reach their peak storage volume sometime after the flood peaks.

Flood-induced catchment changes. Landslides and changes in river morphology can significantly change the level of protection afforded by defence systems. Landslides can form natural dams and storages that will almost always ultimately breach inducing additional flooding after the main flood event that might overwhelm defences that are still under stress from the primary event. For example, a flood detention dam that has absorbed a flood peak and is now full will be prone to any sudden inflow from an upstream landslide dam failure. Active flood defences such as flood storage dams also need to be emptied in a timely manner after the primary event to reinstate their purpose but this process of emptying places ongoing stress on downstream defences, can take considerable time and may hamper recovery phase operations. Sedimentation of the river from flood induced deposition can measurably change river hydraulics and hence shift the high-risk location within the existing defence system. Telemetry equipment on river systems can be impacted and in extreme scenarios damaged or lost, as occurred in the 2015 flooding in Cumbria, England, compromising the ability to issue flood warnings and compromising record keeping and data collection.

Post flood stressing of coastal flood defences. Many flood defence systems are associated with the protection of property in low lying flood plain settings on the coast. Tidal conditions add cyclic, post flood stressing to these defence systems that may have been partially compromised during the main event. This issue can be further complicated by flood induced changes in estuarine or coastal morphology and associated hydraulic conditions. Tidal cycles can also hamper efforts to progress recovery processes including interim and permanent repairs; for example, any breached section of a coastal flood defence may experience cyclic overtopping from tidal

influence further exacerbating the existing situation and compromising repair attempts. Such situations may also continue to increase the amount of material that needs to be managed e.g. each tidal cycle could deposit more sand in the impacted areas. Additionally, the weather systems can result in storm surges on top of the forecast tide levels, further contributing to the impact.

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CHAPTER 5

Flooding threats

Key messages:

- **Understand flood threats to inform action**
- **Vulnerability assessment is essential**
- **Strategies should be targeted at specific threats**
- **Building resilience is multi-pronged**

Figure 5.1: Structure of the handbook

Other places to find information on the topics in this chapter

Chapter 2: impacts on the institutional setting of various flood characteristics

Chapter 3: impacts on preparedness of various flood characteristics

Chapter 4: impacts on response of various flood characteristics

Chapter 6: impacts on flood defences of various flood characteristics

Chapters 8 to 12: details of the process and what needs to be done in the response, given the limitations imposed by the flood characteristics, starting from early warning and inspections, to assessing potential failure mechanisms, to selecting emergency measures as well as sorting out the logistics and implementing the measures during an event

Chapter 14: the role of reliability analysis in understanding how to improve response, given the flood characteristics

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Note:

The Reader is kindly requested to take note of the Disclaimer on page ii of this handbook.

Chapter title page photograph:

Coastal threat necessitating emergency protection (courtesy: USACE)

Key messages

- **Understand flood threats to inform action plans.** For each flood threat, there should be clear focus on analysing contributing factors, developing and using forecasting models, and protection measures. Flood threats arise from a wide range of flood types, each with unique causes, impacts, and vulnerabilities.
- **Vulnerability assessment is essential.** Different communities and infrastructure elements face varying degrees of risk depending on their location and surrounding environment. The chapter highlights the importance of identifying vulnerable populations and infrastructure to prioritise protection and support.
- **Target strategies at specific threats.** A "one-size-fits-all" approach wouldn't work for managing diverse flood threats. The chapter advocates development of specific strategies tailored to each type of flood, considering its unique vulnerabilities and risks.
- **Build multi-pronged resilience.** Mitigating flood impacts goes beyond physical infrastructure and includes sustainable land use, public awareness, early warning systems, social and economic support, and community rebuilding initiatives for comprehensive flood resilience must be promoted.

This chapter discusses the forecast of hydro-meteorological events causing water-level rise and the generation of waves, leading to river and sea floods and potential threats for flood-defence structures (see Table 5.1). Tsunamis, landslides, dam breach or human error may also cause floods but are not the primary subject of this handbook. In smaller water bodies, like lakes, the difference between water inflow and outflow plays an important role. The focus of the chapter is on flood types, and their relevance to emergency management through the concept of flood-related threats.

The subsequent sections of this chapter address:

- Section 5.1 – flood hazards, characteristics and threats.
- Section 5.2 – flood characteristics in their geographical context
- Section 5.3 – understanding of flood threats.
- Section 5.4 – probability of flood threats and relationship to emergency response.
- Section 5.5 – flood characteristics and flood threats.
- Section 5.6 – other flood types.

5.1 Flood hazards, characteristics and threats

In the context of this chapter, a flood-related threat can be seen as one which either contributes to the hydraulic load on a flood defence or affects the emergency management of that defence. It is important to note that the concept of a flood-related threat follows from the predominantly meteorological event preceding the occurrence of the flood, combined with the geographical situation. The event largely determines the severity of a flood and its flood-related threats in relation to the integrity of the flood defence and emergency measures to be taken; it is often the trigger to start the early response phase of emergency management.

Table 5.1 Examples of hazards leading to river, sea and lake floods, flood threats and potential inundations.

Hazard source	Type of threat
Sea	Strong wind-driven (tropical) storms leading to the temporary rise of sea levels (storm surge). Storm associated winds, causing waves (wave attack). Tsunamis arising from earthquakes.
River	Precipitation translating into high river discharge and river-flood levels. Snow melt (idem). Ice jams, causing backwater. Sudden water release from reservoirs, either operational or as a result of reservoir-dam failure.
Lake	Strong winds will lead to tilting lake-water level (and in the case of variable winds also to oscillations such as seiches), low water levels at the lee side of the lake and high-water levels at the windward side. High (river) discharge into the lake.

In this context a flood refers to a high water-level situation in a river or at sea, where inundation is referred to as the generally undesired inundation of land leading to damage. Colloquially, the word flood is often used to mean such inundation.

For emergency response, the important characteristics of a flood are development and timing, duration, water flow, water levels and wave conditions together with the uncertainties in these characteristics. Other chapters elaborate further on related organisational (particularly chapters 2 and 3) and technical (chapter 6 and 9) impacts of these flood characteristics.

5.1.1 Adverse weather

Adverse weather can be seen as the primary cause of flooding. It also represents a threat to emergency management as it hampers many aspects, including preparation (affecting infrastructure and making it difficult for staff to reach their destination in time), evacuation, safety and reliability of inspection and emergency measures, rescue and recovery, There are many types of adverse weather, including for example strong winds, heavy precipitation, thunder/lightning, poor visibility, snow/ice, etc.

5.1.2 Lead time and predictability

For emergency management, it is important to know where and when a flood will strike. National hydrometeorological services play or should play a key role in real-time monitoring and forecasting of these hydrometeorological phenomena, and in providing warnings which can serve as triggers for emergency organisations to become active.

A flood warning well in advance allows more time to prepare and take appropriate emergency measures to prevent or at least mitigate flood impact. Lead times range from hours to days. At an early stage, uncertainties on the occurrence and scale of the flood are high. However, the quality of the prediction of flood parameters like arrival time, volume and location become more accurate during the build-up of the flood. Important issues here are how accessible are long roads for emergency measures and evacuation.

5.1.3 Duration

The duration of a flood is important as it affects several factors important for emergency response: accessibility of flood defence structures for inspection and emergency measures, time-dependent deterioration of the actual flood-defence capacity, e.g. erosion and weakening of soil resistance, availability of equipment and

manpower, duration of evacuation. The duration of a sea flood ranges generally from 1 to 2 days, whereas floods in rivers vary form hours in the upper basin to weeks in the lower basin and delta and more than a month for the very large deltas of e.g. the Brahmaputra and the Mekong.

5.1.4 Water-level rise

Obviously, the *higher* the water level, the bigger the flood threat. High water levels are the primary flood threat for the flood defence itself, but also for emergency management. The water levels determine water pressure, build-up of soil-weaking pore pressure, degree to which infrastructure inspected, accessibility for emergency measures, potential overflow of flood-defence structures, the availability of evacuation routes and the extent of inundations.

Apart from the waves the water-level rise of the sea, storm surge, may be of the order of 2 to 5 metres in moderate climates. In estuaries, which narrow as they get more distant from the coast, the intrusion of the sea-water storm surge increases even more. Typical tropical storm surges in more extreme climates are in the range of 3 to 5 metres, although historical tropical storm-surge observations show records of 6 to 10 metres. For example:

- In the 1970 Great Bhola Cyclone in Bangladesh (although it is difficult separately to identify the surge water levels and the waves);
- The highest recorded surge of over 14m in 1899 in Queensland, Australia.

The water-level rise in rivers differ greatly from basin to basin and location within each basin, but depending on their location, range up to 10 metres.

The *faster* the water level rises, the shorter the time to inspect, monitor and to respond adequately to flood impacts. At sea, the build-up of high-water levels because of a storm is smooth and relatively fast, linked to the typical storm duration of one to two days, and accelerated or decelerated by the tide. In the upper basin of rivers, the typical time for water-level rise is only hours, whereas further downstream a few days is more representative.

Rapidly rising water levels are generally accompanied by strong currents that may erode banks, shores and flood defences and pose a risk to rescue operations.

5.1.5 Wave heights and forces

An important and complex flood characteristic is the presence of wind waves, and the effect of these waves can be important for the integrity of defences and in emergency response. Waves contribute to erosion of foreshores and shorelines, exert forces on flood-defence structures, run up and overtop flood defences, causing direct inundation damage or worse erode the flood-defence structure leading to breach. Waves (and wind) affect the safety and reliability during execution of the emergency measures.

Wind-generated waves can vary greatly in height, depending on climate, flood type and water system. On rivers, typical wind wave heights may be no more than a few decimetres but may occasionally exceed 1 metre if a severe windstorm occurs on a large river during a river flood. On large lakes (say greater than 100 km²) wave heights may exceed one metre height from 7 Beaufort wind on and may reach 2 metres and more during severe windstorms unless the lake is only a few metres deep. Along the coast, waves heights may exceed 10 metres offshore but may reduce to roughly half the water depth once they reach shallow water. Cavaleri et al. (2007) provide a reliable state-of-the-art review of waves and wave modelling.

Besides wind-driven waves, longer period waves may add to the risk to flood defences; although lower in height than local wind waves,

their high energy can cause significant overtopping at flood defences. Types of longer period waves include the following:

- Swell, which is the most common of these longer period waves. These are waves which originate from distant storm activity.
- Infragravity waves, which typically occur at the coast in combination with other waves and have amplitudes up to about one metre and periods of order one minute. The risk to defences is mainly related to the gradual total water level variations associated with these waves.
- Seiches, which are typically associated with large and sudden wind variations that occur in lakes and some estuaries; they tend to have wave periods from several minutes up to a few hours and larger amplitudes than infragravity waves.

Tsunamis are out of the scope of this handbook, not being of hydrometeorological origin, although section 5.6.3 provides a brief introduction.

5.2 Flood characteristics in their geographical context

5.2.1 Overview of flood threats in relation to their geographical situation

Table 5.2 summarises the flood characteristics described above in their geographical context. The description is general and indicative.

Table 5.2: Typical flood characteristics for each geographical position of coastal or fluvial flood defence. Depending on a specific geographical or meteorological context the characteristics will deviate from this table.

	Characteristics of flood				
Geographical location	**Lead time (Longer/shorter)** **Predictability (Better/worse)**	**Duration (Longer/shorter)**	**Water level rise (Faster/slower)**	**Water level rise (Smaller/larger)**	**Waves (Smaller/shorter; higher/longer)**
River upper basin	Generally short lead time of a few hours. Considerable uncertainty in precipitation volume and (actual) related discharge. Uncertainty in weather forecast leads to uncertainty of location and flood volume.	Generally short duration: hours to a day, flash-flood type.	Generally fast flood-level rise, strongly depending on saturation and retention or absorption capacity. Strong currents.	Can be very large in narrow valleys, several to more than 10 metres is possible	Waves on top of the water level are not of significance
River middle basin	Of order of one to several days. Upstream situation is the primary warning for the middle basin, considering the different travel times of flood peaks in the tributaries and the resulting combined water levels when they coincide. Local precipitation or snow melt may reduce lead time.	Days, depending on the volume passing from upstream and coincidence or sequence of floods in tributaries.	Generally slower than in the upper basin. Special attention required near confluence of tributaries	relatively narrow river valleys may cause considerable water level rise.	Possible smaller waves in the order of maximum 1 metre or less.
River lower basin	Relatively good predictability: several days to a week. Prediction depends largely on upstream flood and communication of flood situation to downstream flood-defence authorities. Little influence of local precipitation.	Week to over a month. Depending on the size of the river basin and the extent and/or development of the floodplains, duration will vary.	A few days to a week or even longer. Depending on the size of the river basin and the extent and/or development of the floodplains, water-level rise will vary.	Several to more than 5 metres. Depending on the size of the river basin and the extent and/or development of the floodplains, water-level rise will vary.	Waves and wave forces are very limited, since there is also a limited wind fetch. Still waves from 0.5 to 1 metre must often be considered.

	Characteristics of flood				
Geographical location	**Lead time (Longer/shorter)** **Predictability (Better/worse)**	**Duration (Longer/shorter)**	**Water level rise (Faster/slower)**	**Water level rise (Smaller/larger)**	**Waves (Smaller/shorter; higher/longer)**
Estuary	Day to several days. River sections in the delta and estuaries are closer to the sea, flood situations will also depend on conditions at sea. Peak water levels and waves depend on storm predictions.	Shorter than in the lower basin, but longer than a sea defence. The flood is generally a combination of high river discharge and storm surge. Peak will be short, but the river flood may cause sustained hydraulic load.	Relatively slow and gradual river water-level rise, but faster rising peaks because of storm surge.	Several metres, but in narrow estuaries the combination of tide and storm surge may exceed 10 metres.	Waves and wave forces may occur near the coast and in the generally wider estuaries. Wave height remains generally limited to one or maximum two metres.
Coast	Day to several days. Meteorological services monitor the formation and track of storms developing over oceans and seas until landfall. Uncertainties arise from changing storm tracks (where will be landfall) and storm force development.	Hours to a day or two as the storm passes.	Water-level rise is relative fast, with the duration of the storm possibly accelerated by coincidence of the tide. Extremes occur with fast moving tropical storms.	Generally, a few metres in moderate climates and 3 to more than 5 metres with tropical storms. Few historical recordings to 10 metres and more	Long and high waves need to be considered at sea transforming into a relatively complex situation nearshore. Wave heights depend largely on wind fetch and nearshore depth. Maximum wave height about half the water depth.
Lakes	Days to several days, with considerable uncertainties. Water level depends on many factors: inflow from rivers and pumping stations, outflow possibly limited because of downstream high-water levels, local wind conditions	Where wind is dominant in shallow lakes, one or two days of high levels. Lasting high inflow and limited outflow may prolong the flood levels to many days and more than one week.	Depending very much on size/area (inflow/outflow) and depth (wind). In the case of wind, a serious water-level rise can be expected in one or two days.	Water level rise tends to be moderate compared to rivers. Wind setup in relatively shallow lakes may yield almost twice the regular water depth (tilted water surface).	Depending on the size and depth of the lake, waves need to be seriously considered. A long wind fetch will yield relatively high waves, limited to half of the water depth, that is increased by wind setup.

5.2.2 Climatic, physical and occupational context

The combination of the nature of these flood hazards and their geographical context largely determines the flood characteristics. The geographical context determines to what extent a river or coast is vulnerable to flood threats and the need for flood protection and emergency measures. There are several factors of importance here.

- **Climate and typical weather conditions** for a region determine the nature of storms and precipitation potentially leading to sea and river floods (Figure 5.2 and Figure 5.3). The climatological context is important because of its influence on the prevailing weather systems and their seasonality. Depending on the geography, snow cover and ice jams may add to the flood risk.
- **Natural, physical terrain**. The regional geography and exposure of the population and intensity of its socio-economic activities (Figure 5.4). Within each river basin, a distinction can be made between upper, middle and lower zones as well as the coastal zone (section 5.2.3 to 5.2.6).
- **Urbanisation and the related presence of flood-defence infrastructure**. The impact of sea and river floods becomes more serious in areas with more urbanisation and human interest. A general but not universal trend is that urbanisation increases from the source to the sea and that in the lower, flatter regions more flood-defence infrastructure will be present and all together a stronger need for emergency response for flood defences.

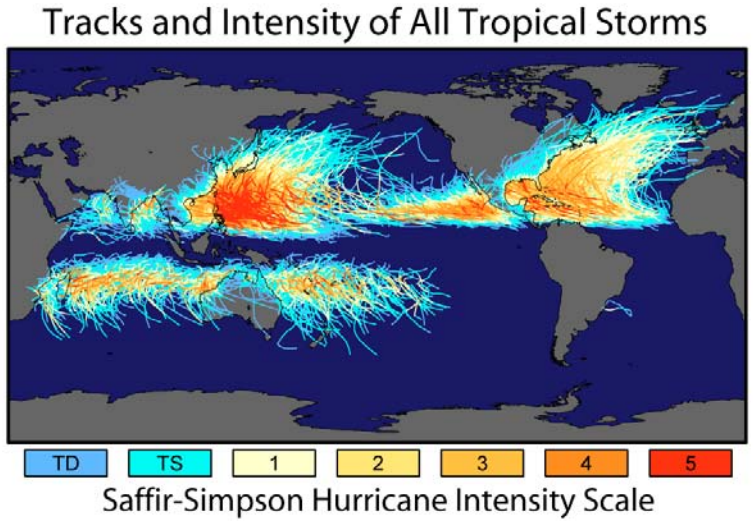

Figure 5.2: Tropical storms, tracks and intensity (Saffir-Simpson scale) (source: NASA Earth Observatory)

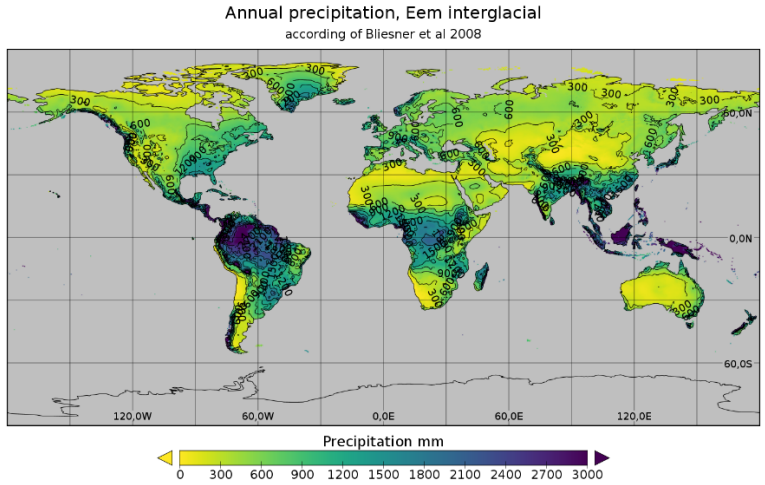

Figure 5.3: World precipitation map (source: EMM, Bliesner)

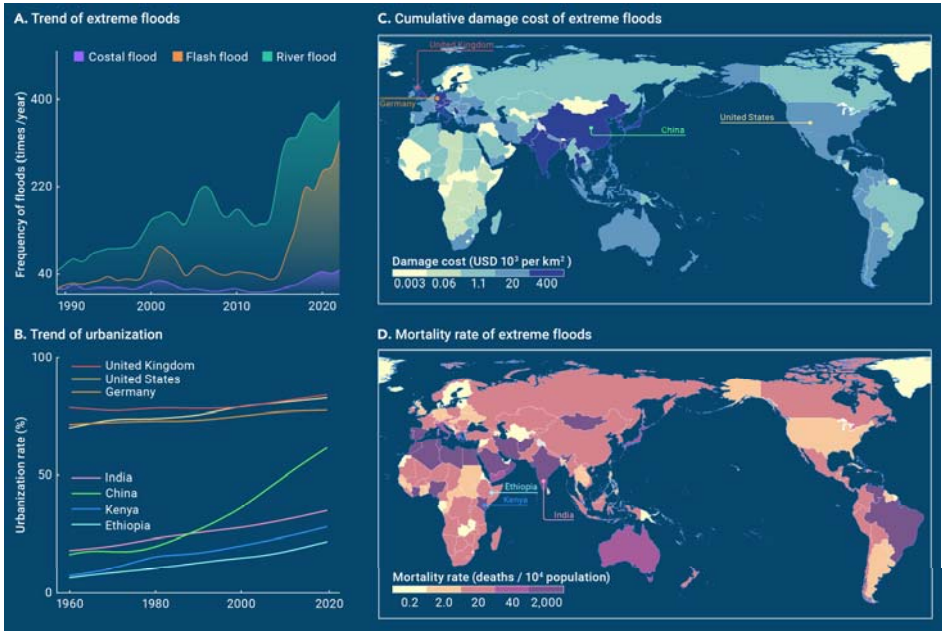

Figure 5.4: World map indicating types of floods, flood-related damage and mortality, suggesting relationship to population growth and urbanisation (source: Yang et al., 2023)

5.2.3 Parts of the river basin flooded by precipitation and melt-water

A river basin or watershed can be defined as the geographical area "from source to sea" that drains its rainwater or melting water into the sea. Geographically, we may distinguish sub-basins for a particular tributary flowing into the main river. In general terms we distinguish the steeper *upper basin*, the gentler sloping *middle basin* and a hardly sloping, rather flat *lower basin* in which we will find the transition to the *sea* in a *delta* or *estuary* (see Figure 5.5 and 5.6).

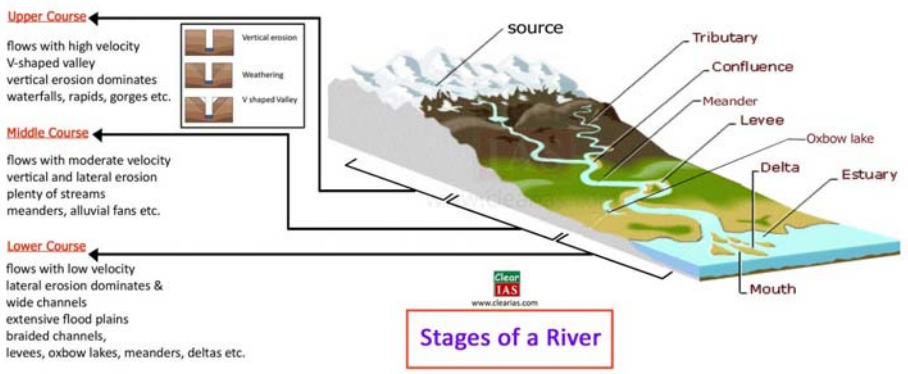

Figure 5.5: General overview of a river from the source to the sea. A meteorological event like heavy precipitation will lead to floods and serious direct flood threats in the upper basin, where in the lower basin such precipitation will generally not lead to a river flood and threatening inundation (source: ClearIAS.com)

The **upper basin**, the river source is often characterised by a mountainous or hilly rocky or stony area, with relatively low average but highly-variable and rapidly-responding water discharges and variable but overall relatively high flow velocities. The river often follows narrow valleys, and the riverbed will contain stones or even boulders, and bigger types of gravel. These areas are often less densely populated, although houses are often close to the river itself. Flood-defence structures are generally rare except for some smaller dedicated structures. Effective flood regulation in these areas is most often through reservoirs, since relatively small flood volumes may still be manageable. The state of the vegetation cover determines to a significant extent the absorption capacity of this part of the basin in case of extreme precipitation. Deforestation leading to rapid runoff of rainfall is an important issue that will contribute to rapid river flow causing increasingly extreme threats in particularly the upper and middle river basin.

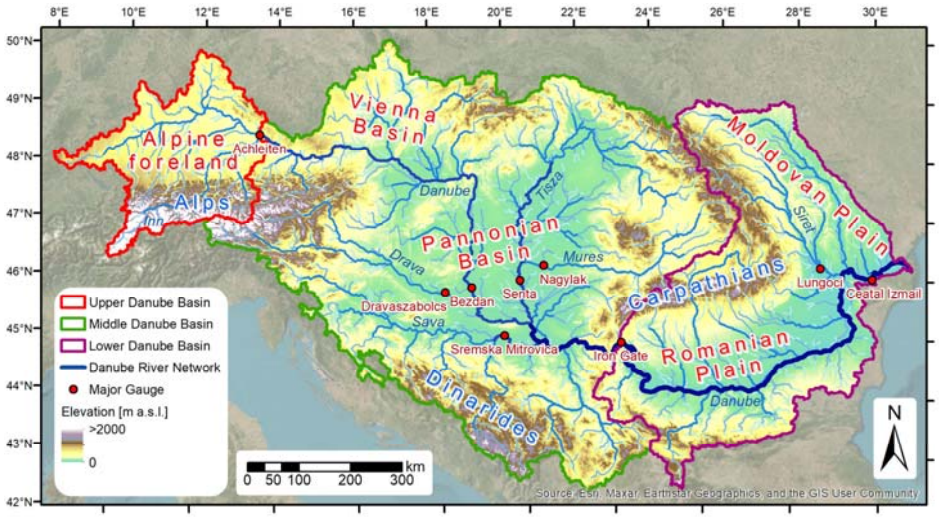

Figure 5.6: Danube with its upper, middle and lower basin (source: Probst and Mauser, 2023)

Floods in the upper basin occur due to heavy rains, either from lasting low-pressure areas (e.g. Central Europe) or tropical storms halted by mountain ranges (e.g. Philippines, Vietnam, Japan).

In the **middle basin** rivers have merged and collected more water to discharge. The resulting flow is slower in a wider riverbed that is of gentler slope than further upstream. Over ages the river has generally determined its own riverbed in the valleys of often relatively gentle hilly areas and made its way through or around harder rock or soil layers; in the latter case the valley can narrow while the currents can increase.

Floods in the middle basin occur due to upstream flooding, with coincidence of floods from tributaries merging leading to extreme events, sometimes aggravated by more local influx.

The extent of the natural dynamics of rivers in the middle basin may depend on the extent of urbanisation and flood defences. Naturally dynamic rivers may exhibit sudden changes in course and in the riverbed and unexpected river floods may arise in smaller and/or old riverbeds.

Flood risk management measures in these middle stretches of the river are often a combination of flood retention and detention areas and growing flood defence systems.

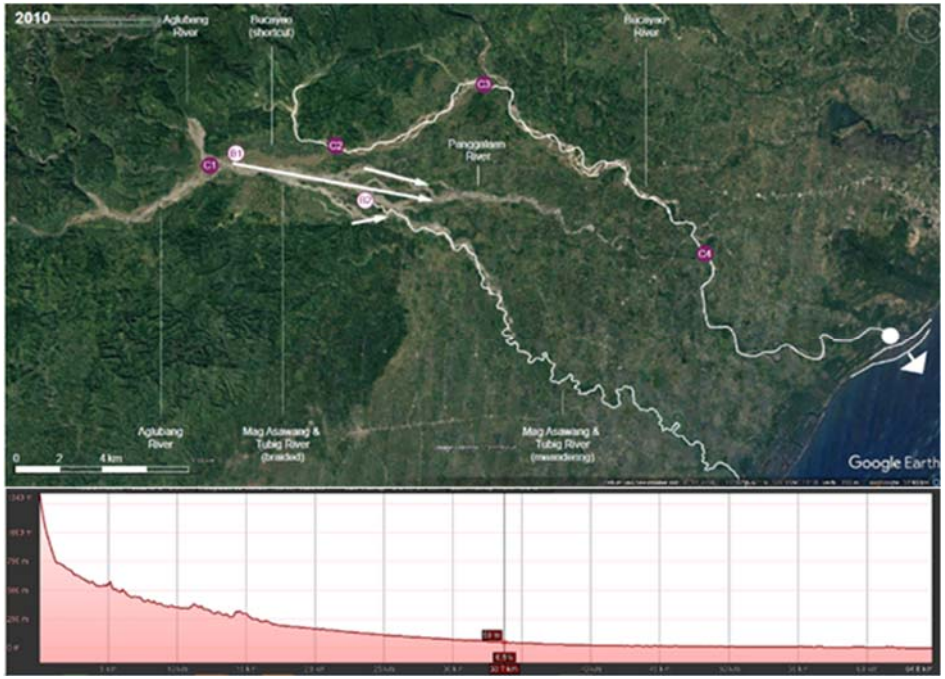

Figure 5.7: Mag-asawang Tubig basin on Mindoro Island Philippines. Very steep upper basin, braiding, unstable middle basin and river and sea flooding in the lower basin (source: Royal HaskoningDHV)

The **lower river basin** and **deltas** are characterised by very mild slopes (10 cm to 1 m per km). In contrast to the upper and middle basin, in this lower part it is the river that has created the landscape. The river carries mostly sand and clay, constantly creating new channels and

abandoning others, especially in cases of high river discharge due to displacements of large quantities of sediment.

Thus, the rivers have created a fertile area, initially used for agriculture. Such areas may well be urbanised, accompanied by efforts to regulate the river and construction of flood defences, thereby constraining the natural course of the river.

5.2.4 Estuaries or transition areas influenced by river floods, tide and storm surge

An estuary is a partially enclosed coastal body of fresh to brackish water with one or more rivers or streams flowing into it, and with a free connection to the open sea. Estuaries are formed when freshwater from rivers and streams mixes with saltwater from the ocean and where tidal currents are strong enough to prevent most sediment to be locally deposited and accumulated, instead transporting it to the sea. Estuaries may have very different geomorphological forms. This includes the river mouths in deltaic areas, but also the typically funnel-shaped river mouths.

Extreme high-water levels in estuaries originate from a coincidence of high river discharge and storm surge. In many areas the rainy season generating river floods coincides with the storm season generating storm surge. Hence with long duration river floods, the occurrence of a storm is also probable. The combination of high tide and storm surge will result in extreme water levels and in wider estuaries wind-generated waves will add to the flood threat.

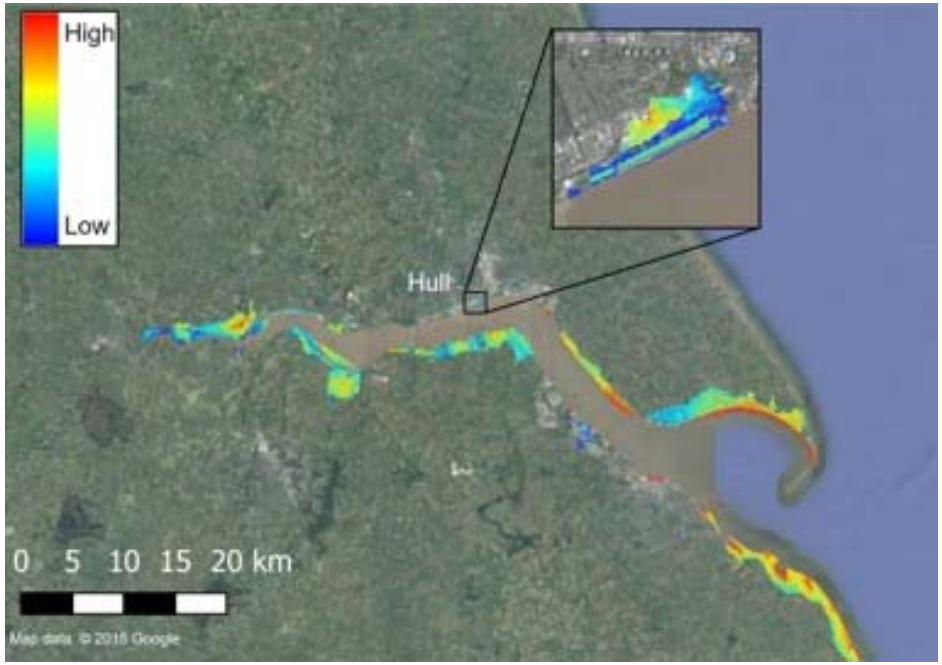

Figure 5.8: Depending on the storm surge and the geography of the floodplains near the estuary, the flood extent will vary. Here a flood-risk map for the Humber Estuary near Hull, UK (source: Yablonski & Blair, 2019)

5.2.5 Sea and coast floods from storms

Coastal floodplains may be shielded from the sea or ocean by natural or artificial coastal defences.

Since coastal flooding is often of a much more severe nature than river flooding and more difficult to contain, people migrate to locations near the coast where natural protection prevails such as areas with dunes, or, in tropical zones, mangroves.

However, in many places, coastal flood defences have also been erected and reinforced to provide safety. In some countries these defences have reached enormous dimensions over the last two centuries

and provide relatively robust protection (Europe, parts of the US, Japan). In many other countries, protection from coastal flood defences is at a much earlier stage of development and provides limited protection with relatively frequent flood defence breach and flooding, e.g. Vietnam, India. Whatever the flood defence type, storm surge in combination with high tides and high wave loads may still result in failure of the flood defence system and subsequent inundation of the coastal flood plain by seawater.

Figure 5.9: Low sea defence in Nam Dinh province Vietnam (courtesy: Michel Tonneijck, Royal Haskoning DHV)

Figure 5.10: Closure works of 800 m wide flood embankment breach in Nam Dinh province (Vietnam) after the typhoon Damrey (29 September 2005) The picture was taken on 2 November 2005 under storm conditions (courtesy: Michel Tonneijck, Royal Haskoning DHV)

For coastal defences the climatic zone determines the force of the attack and the flood threat. In temperate climate zones, strong storms may generate sustained wind speeds of 20-35 m/s and the corresponding storm surge (several metres) and waves on a regular basis (several times per century or even per decade). Tropical storms (cyclones, typhoons,

hurricanes[1]) exceed these winds speeds with velocities up to 30-60 m/s, and storm surge heights frequently exceeding 5 metres. The heights of wind-generated waves can in both cases exceed 10 metres in deep water, but the nearshore bathymetry will cause waves to break. Hence the actual wave attack will not primarily be climate dependent, but rather location- and bathymetry-dependent.

In terms of flood threats, important factors are:

- Storm surge, particularly when open-coast magnitudes are amplified as the surge is constrained within narrowing inlets and estuaries (Figure 5.11).
- Wind waves which attack the slopes of dunes and coastal defences, causing erosion and overtopping and eventually leading to breach (see Figure 5.12).

Figure 5.11: Flood extent from numerous estuary flood defence breaches, 1953 North Sea Zeeland Flood, raised water levels in the sea arms of Zeeland Province (source: nl.wikipedia.org/wiki/Watersnood_van_1953)

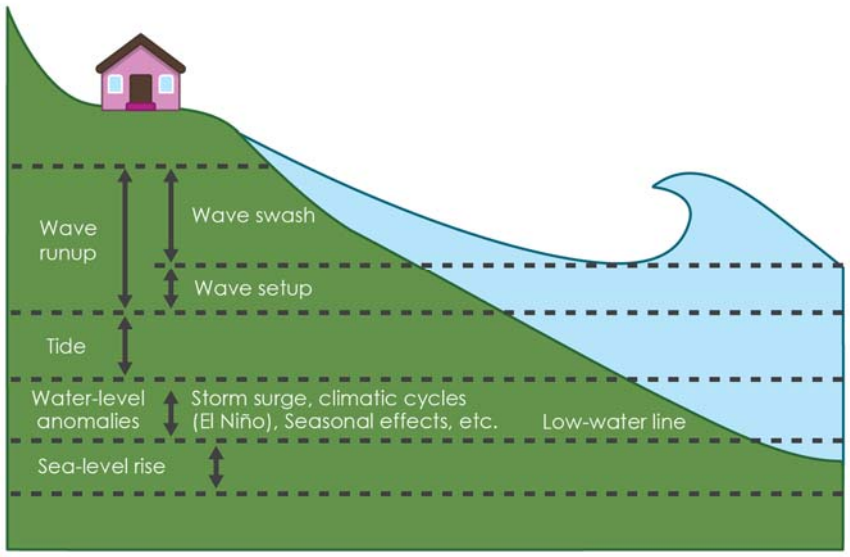

Figure 5.12: Factors composing the flood threat for sea flood defences (source: Vitousek et al., 2017)

5.2.6 Lakes, flood threats determined by inflow/outflow ratio and wind

For lakes, lowland lakes, reservoirs and to a lesser extent also canals, surrounding flood defences often have a dual function: retaining the enclosed water shielding any surrounding flood prone land. For such situations, two specific factors pose a threat to the effectiveness of flood defences:

- Greater inflow than outflow: Lakes are generally fed by one or more rivers, determining the influx of water, where outflow is generally via one river or sluices where the lake is formed by a dam. Smaller

[1] Tropical storms are referred to depending on their geographic location: *hurricanes* are tropical storms that form over the North Atlantic Ocean and Northeast Pacific, *cyclones* are formed over the South Pacific and Indian Ocean and *typhoons* are formed over the Northwest Pacific Ocean.

contributions to the influx are from smaller local streams discharging into the lake and pumping stations. Elevated inflow and hampered outflow may cause flood threats, depending on the area and storage capacity in the lake or reservoir.

- Wind set-up/seiche: Local storms may cause considerable wind setup (see e.g. Figure 5.13), significantly adding to the elevated water level and flood threat. With sufficient wind fetch, wind waves add to the flood threat, even though the wave heights may be limited by the available water depth. In the case of variable winds, wind set-up oscillations can develop which may experience quasi-resonant amplification at the eigen periods of the lake (seiching).

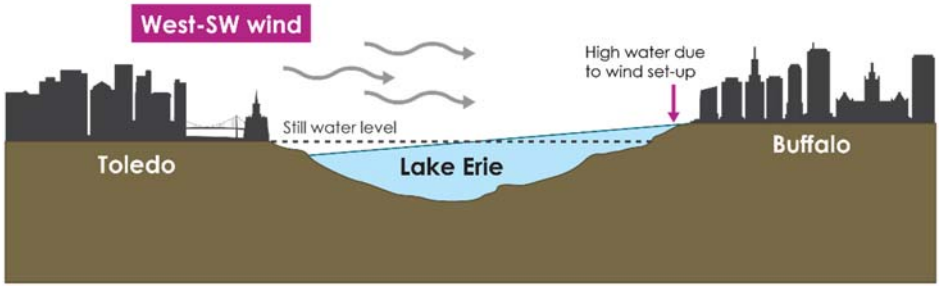

Figure 5.13: Wind setup in Lake Erie adding to flood threats in Buffalo (source: US National Weather Service, Cleveland Ohio)

5.3 Understanding flood threats: expect the unexpected

Understanding the phenomena leading to a flood threat to the flood defence and the protected area behind is key to every stage of flood emergency response. Flood defences are designed only to provide protection up to water level and wave height of a certain small probability of recurrence. Emergency management certainly comes into play for extreme events near or beyond these design conditions.

However, emergency management during more common but less extreme situations is equally important since flood defences may well fail in less severe conditions than those for which they are designed. In many cases of (unexpected) dam or flood defence failure, the cause is not just the design load being exceeded, but rather a combination of the high load with several other factors that are unfavourable to the assumed strength of the flood defence.

Unexpected combinations of human error, inadequate design, hidden mistakes during construction or degradation of the flood defence structure and external influences like animal burrowing, floating objects may cause the flood defence to be weaker than assumed.

Figure 5.14: Beaver burrow in embankment (courtesy: Regional Water Authority Aa en Maas, Netherlands)

Figure 5.15: Flood damage of the Boscastle Flood in 2004 (source: https://commons.wikimedia.org/w/index.php?curid=999149)

Floods are rarely an exact replica of previous floods. This makes it even more important to understand how floods typically unfold, especially for emergency management, but also for design. It is also important to know to what extent design assumptions correspond to the actual way floods unfold.

Differences between floods and their impact also occur because both physical coastal or river-basin conditions and flood-defence properties will change over time. Reasons for changes include:

- Coastal or bank erosion, which may have decreased the defence zone.
- Change of vegetation and land use, which may have increased exposure and vulnerability to floods.
- Land subsidence, wear or deterioration affecting the flood defence
- Differences in coincidence of flood peaks of tributaries.
- Differences in antecedent soil conditions (already saturated before the flood event, or not).
- Differences in upstream retention, for example due to failure of upstream flood defences.
- The addition or modification of flood defence structures in one location in a river system, creating consequential threats to existing structures elsewhere.

All these examples illustrate that the emergency response during any particular flood should be adjusted to the actual circumstances.

5.4 Probability of flood threats and emergency response

The natural weather/meteorological events underlying floods leading to threats for flood defences and subsequent inundation recur with a certain statistical probability. It is important for emergency managers to understand the frequency and magnitude of various floods to be better prepared (see Chapter 3) for emergency response (see Chapter 4).

The probability of occurrence of river floods is also important for the general management of emergency response. Figure 5.16 shows an example characteristic curve for the relation between water levels and the frequency of their occurrence in rivers: the level difference for a factor 10 in frequency is often less one metre. Particularly for the extreme return periods, the differences can be very small and for emergency response in fact negligible. To this must be added the uncertainties in many situations (e.g. where the available record to generate flood statistics is rather short). Such small differences in water levels/wave conditions for different return periods, with the associated uncertainties

(whilst undesirable), may be helpful in reducing the number of scenarios which the emergency manager needs to consider as part of preparedness

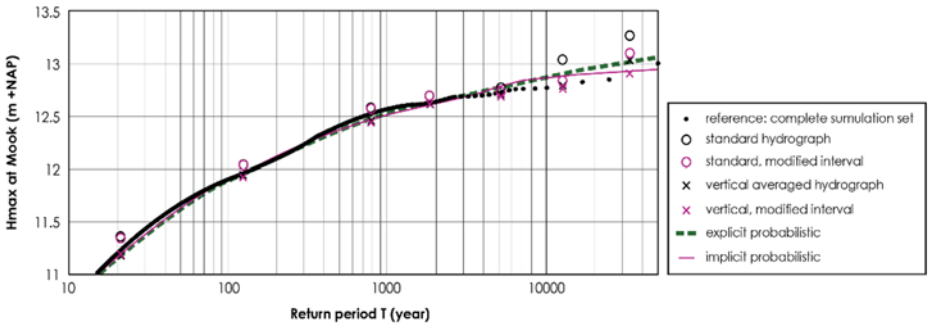

Figure 5.16: Frequency of potential river-flood levels of the Meuse river in the Netherlands, situation 2015 (source: Morales-Napoles et al., 2015)

Knowing that a flood defence may well start to fail below the protection level and that water levels may show un unexpected additional rise, the 上の graph shows that emergency response needs to be initiated far more often than would be necessary for the adopted flood-protection level. Referring to Figure 5.16, suppose that the design flood-protection level is 1000 years (12,5 m), but that the flood defences may start to fail or have an increasing probability of failure (see discussion of fragility in Chapter 3) when the water is rises above e.g. 11,5 metres (return period 40 years), evacuation may need to be triggered. This implies that, unless the flood defences could be secured, evacuation would need to be ordered with a probability of about 20% in a period of ten years and even more than 50% in a period of 30 years. This example shows the importance of adequate emergency management of flood defences, particularly if emergency measures can prevent the drastic measure of evacuation.

5.5 Flood characteristics and flood threats

This section provides a general description of how the flood characteristics described in the previous sections translate into threats for direct flooding or for the integrity of flood defences. Table 5.3 provides a summary of these threats, and this is followed by more detail on some of these. More technical detail about threats to the integrity of flood defences is given in Chapter 9. Issues associated with actual emergency techniques and measures are discussed in Chapters 10 and 11.

Table 5.3: Flood characteristics leading to flood threats and potential flood-defence failure

	Flood threats			
Flood Characteristics	**High water level** **Direct inundation**	**Erosion of bank, river/sea bed and/or flood defence** **Movement of damaging debris**	**Overflow and overtopping**	**Water intrusion** **Soil weakening, geotechnical failure**
Lead time (*Longer/shorter)*	Short lead time reduces probability of emergency protection measures and evacuation	Longer lead time allows for emergency bank or slope protection	Longer lead time allows for emergency raising of flood defence	Longer lead time allows for emergency slope sealing or other preventive measures
Duration *(Longer/shorter)*	Increased threat, bigger volumes of water are more difficult to counter in an emergency Higher risks of flood-defence failure	Longer duration of flow, means higher risk of dangerously progressing erosion	Longer duration increases risks from extra water level rise (oscillations, seiches, water discharges) emerging wind waves. Emergency measures may not hold long enough and sustained overtopping water will cause more erosion.	Long-lasting floods cause more and further water intrusion, higher pore pressures, more reduction of geotechnical stability and slow inundation of hinterland, hindering inspection.
Water level rise *(Faster/slower)*	Faster water level rise reduces possibilities for emergency measures	In general, rapid water level rise occurs in fast flowing rivers, with higher flow velocities and freeing of debris, both causing erosion	Fast rising water levels bear uncertainties on maximum and reduces probability of emergency raising	Faster water-level rise reduces time for inspection and preventive measures.
Water level rise *(Smaller/larger)*	Higher water levels increase risks of direct inundation and/or breach of flood defences	Erosion more influenced by flow velocity rather than flood level. Higher, less frequent water levels may impact new erosion points	Higher flood levels increase risk of overflow and also of overtopping when wind waves emerge	Higher flood levels increase water head, the trigger for intrusion and cause higher pore-water pressures and raise the risk of loss of geotechnical stability.
Currents and flows (faster/slower)		Erosion strongly influenced by flows and velocities. High velocities may move sediment and debris to damaging situations	Rapid deposition of sediment and debris can cause rapid increases in riverbed levels resulting in increased risk of defence failure due to overflow/overtopping	
Waves (higher/smaller; longer/shorter)	Bigger/higher waves may lead to the breach of an embankment (overtopping, land side slope erosion)	Stronger wave attack will increase erosion risk	Higher and longer waves increase overtopping rate	Higher waves may have some influence on water intrusion, may cause hinder for inspection and emergency measures.

5.5.1 Direct inundation

Floods may occur at places where no direct flood defence is present. Extreme water levels may undesirably inundate valuable land.

5.5.2 Erosion, sedimentation and movement of damaging debris

Strong currents and debris released due to floods may erode riverbeds and damage and erode riverbanks and flood defences where they lack protection. Bare riverbanks or grass-covered earthen embankments may not withstand the eroding forces. Emergency measures should be focused on temporary protection and removal of potentially damaging objects.

Debris and objects released due to the flood have the potential to:

- Hinder the ability to undertake inspections and constrain observations.
- Damage gates/pump intakes through impact/increased loading.
- Reduce capacity through the blockage (partial/complete) of gates/pump intakes etc.
- Induce changes to hydraulic conditions for example by accumulating on bridges, causing increased upstream water levels and hence the risk of overtopping upstream flood defences.
- Form partial blockages inducing increased flow conditions that may exacerbate the condition of weakened structures.
- Make it difficult to place temporary mitigation measures.
- Delay repairs and recovery.

Sediment released by the flood may cause problems elsewhere in the system. If it deposits out in a river it can locally raise bed levels, thereby increasing water levels at that location and upstream of it for the same flow. Some of these changes may be permanent and require complete re-assessment of the requirements for the crest levels of flood defences. Sediment may also hinder repair and reconstruction work if it needs to be removed before works can advance.

Strong waves may also cause erosion of the foreshore or slopes of earthen embankments. Navigation during a river flood may need to be prohibited to avoid the damaging effect of ship wash.

5.5.3 Overflow and overtopping of flood defences

High water levels exceeding the crest level of flood defences height cause overflow and direct inundation. Overtopping water from persistent wave action may also cause erosion of the landside slope leading to the breach of the flood embankment. Regular or emergency raising may provide an adequate solution if the flood defence can withstand the additional hydraulic pressure.

Figure 5.17: Wave overtopping at Hartlepool (source: floodsite.net, HR Wallingford)

5.5.4 Water intrusion and geotechnical failure

An important flood threat comes from flood water impacting the groundwater pore pressure leading to geotechnical failure of the flood defence. This phenomenon requires professional inspection during the emergency response phase and becomes more serious as the flood lasts.

The higher the water level, the stronger the tendency for water to intrude into an earthen embankment or the subsoil of a flood-defence structure. Underground seepage may cause slow inundation of the hinterland, formation of sand boils from clay-covered sand layers leading to piping and liquefaction of susceptible sand layers. Pore-pressure rise in and underneath the flood defence will weaken the soil and potentially result in loss of stability of the structure.

In terms of emergency response, it is thus important to look for water exiting from the landside slope or near the inland toe of the flood embankment, search for sand boils in the hinterland to prevent the start of piping and carefully watch cracks in flood embankment or other flood defences to determine potential sliding.

Figure 5.18: Advanced geotechnical failure (source: https://www.encyclopedie-environnement.org/en/soil/soil-erosion-story-fluid-grains/)

5.6 Other flood types

The focus of the handbook and this chapter is on hydrometeorological types of flood threats. However, singular, less predictable and rare events like upstream reservoir-dam failure, earthquake-induced tsunamis, earthquakes, landslides, failure of pipelines within the flood embankment, or ship collision may also cause threats, requiring early observation, prompt alert and emergency response. For such events, either flood defences are not directly involved, or the flood types are not directly related to precipitation or storms. However, in some cases the response techniques and measures discussed in Chapters 10 and 11 may still be relevant. On the other hand, some of these alternative types of flooding (e.g. tsunamis, ice jams) can be so extreme that emergency measures for normal flood-defence structures may well not be effective.

5.6.1 Floods from ice jams

Ice jams occur when floating river ice accumulates and impedes further progress downstream with the river current. Ice jams can significantly reduce the flow of a river and cause upstream flooding, sometimes called ice dams. Ice jam flooding can also occur downstream when the jam releases in an outburst flood when the ice dam breaches. In either case, flooding can cause damage to structures on shore.

The flood threats are similar to those discussed in the previous sections of this chapter. The possibility of an outburst, however, requires specialised professionals to assess the strength development of the ice dam holding the river water back and initiate emergency measures on time. Likewise, ice jamming may occur quite fast, leading to fast-rising water levels with flood threats as described in Table 5.3.

5.6.2 Landslides

Landslides may be named as a cause of inundation, but they are also disasters in themselves. Landslides may be regarded as sliding

movements of great masses of soil, often due to long periods of rain saturating mountainous slopes that then slide into a valley. As with ice jams this material may block the flow of a river, leading to water-level rise upstream and eventually the river finding its way downstream of the slide. Consequential threats that may arise from landslides include:

- Rapid loss of water from the downstream river system and risk of drawdown failure to defence embankments.
- Major bed level increases in the river over an extended (months/years) consequential period of high sediment bed loads that may reduce the return period of floods for which the flood defences remain effective.

5.6.3 Tsunamis

Tsunamis are very long waves generated by earthquakes or by (often subterranean) landslides. The likelihood of tsunamis becomes significant from earthquakes from about a Richter magnitude of 7. In the deep parts of the ocean, their propagation speed can be well over 100 m/s, but this speed can be reduced by an order of magnitude when reaching shallow water, increasing the initially small wave height dramatically: the largest tsunamis can have heights well above 10 metres. The first international tsunami warning service was founded for the Pacific Ocean, about 50 years ago. Shortly after the disastrous Indian Ocean Tsunami of December 2004, similar international tsunami warning services were established for the Indian Ocean, and slightly later also for parts of the Atlantic Ocean and Mediterranean. Earthquakes occur, however, with very little or no warning, although there are some early precursors and warnings signs pointing at increased earthquake risk. This makes it virtually impossible to apply emergency measures if they are to prevent flood defences from failure.

Special tsunami defences (effectively very large flood defences) can protect against most tsunamis. After the 2011 Sendai tsunami (see Figure 5.19), Japan commenced a 400 km long scheme of large tsunami defences (Figure 5.20).

Figure 5.19: An often published image of the tsunami wave in Miyako, Japan on 11 March 2011

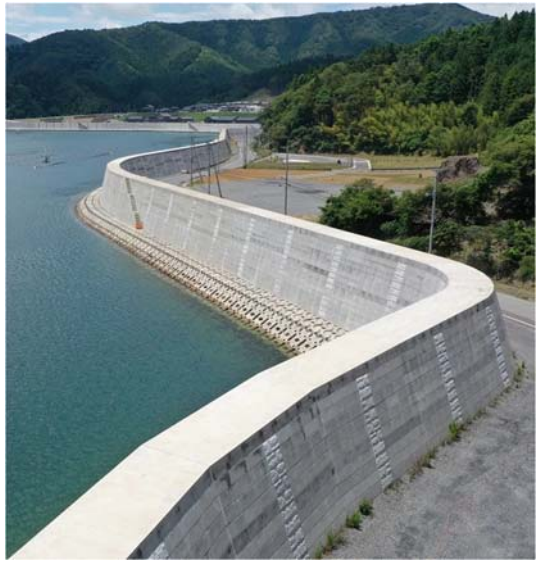

Figure 5.20: Three km long and almost 10 metre high seawall in Japan, Miyagi Prefecture (source: Asahi-Shimbun Newspaper, 2020)

5.6.4 Groundwater flooding

Groundwater flooding typically occurs at a local or regional scale in hilly terrain with thick layers of permeable rock or soil, capable of storing large amounts of groundwater. During extended periods (for this type of flooding typically several weeks or even some months) with large amounts of precipitation, these aquifers can become saturated despite their large capacity. If these aquifers do not sufficiently discharge into rivers, groundwater flooding may occur. This type of flooding has for example occurred in limestone hill regions in Southern England and Northern France, and the duration can be several weeks or even months.

Flood defences are not normally effective for groundwater flooding and hence such flooding is not a common threat to flood defences.

5.6.5 Pluvial, surface or urban flooding

Pluvial flooding, surface flooding and urban flooding all are related to the common concept of floods caused by either surface run-off or by overloading of (urban) sewage systems, rather than floods originating from rivers or other water systems. From now on, the term pluvial floods will be used here.

In a way these pluvial floods are a precursor to river flooding: with intense or prolonged rainfall, first the topsoil gets saturated, after which the excess rainwater flows off the slopes as run-off before it reaches rivers and other water courses. When intense rainfall leads to overloaded sewage systems, the excess sewage water adds to this.

Being direct flooding by precipitation, flood defences are not normally used as a measure to reduce pluvial flooding. As a result, this type of flooding is generally not regarded as a threat to flood defences. However, in some locations very heavy rainfall on an area surrounded by flood defences can raise water levels on the inside of the defences and cause damage.

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CHAPTER 6

Flood defences

Key messages:

- **Flood defences are diverse**
- **Understanding goes beyond construction**
- **Adaptability is useful**
- **Existing infrastructure can be used**
- **Operation and maintenance matter**

	1.	Introduction
Overview Including Governance	2.	Emergency management of flood defences
	3.	Preparedness
	4.	Response
Focus Areas	5.	Flood threats
	6.	Flood defences
Details of Processes and Activities	7.	Communicating for emergency management
	8.	Assessing and inspecting
	9.	Understanding the problem
	10.	Selecting and designing measures
	11.	Techniques for emergency measures
	12.	Logistics and implementation
	13.	Health, safety and wellbeing
	14.	Reliability of emergency measures
Supporting Essentials	15.	Sharing knowledge and collaborating
	16.	Justifying the required funding
	17.	Making it work

Figure 6.1: Structure of the handbook

Other places to find information on the topics in this chapter

Chapter 2: impacts on the institutional setting of various flood defences

Chapter 3: impacts on preparedness of various flood defences

Chapter 4: impacts on response of various flood defences

Chapter 5: link between flood defences and the various flood characteristics

Chapter 8: approach to early warning and inspections for various types of flood defences

Chapter 9: approach to failure mechanism for various types of flood defences

Chapters 10 and 11: approach to selecting emergency measures for various types of flood defences

Chapter 12: approach to the logistics and implementation of emergency measures for various types of flood defences

Chapter 14: the role of reliability analysis in understanding how to improve response, given the flood characteristics

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Note:

The Reader is kindly requested to take note of the Disclaimer on page ii of this handbook.

Chapter title page photograph:

Estuary gate to discharge flood waters to the sea unaffected by tidal currents (courtesy: MLIT)

Key messages

- **Flood defences are diverse**. This chapter emphasizes the variety of flood defence options available, each with its own strengths, weaknesses, and suitability for different flood types and locations. Recognizing this diversity enables informed decision-making about appropriate defence strategies.
- **Understanding goes beyond construction**. While flood defence construction details are covered, the chapter also delves into operation, maintenance, environmental impacts, and integration with other defences. This holistic approach highlights the complexity of flood defence beyond just physical structures.
- **Adaptability is useful**. With climate change increasing flood risks, the chapter explores demountable and te mporary defences alongside permanent structures. This acknowledges the need for flexible solutions that can be deployed quickly and efficiently in various situations.
- **Existing infrastructure can be used**. The chapter identifies existing infrastructure and buildings as potential flood defence elements through adaptation and retrofitting. This showcases the possibility of leveraging existing resources for cost-effective and sustainable flood mitigation.
- **Operation and maintenance matter**. Regardless of the defence type, the chapter emphasizes the importance of routine surveillance, operation, and maintenance. Proactive management ensures defence systems are functional and ready when needed.

This handbook mainly focusses on pure flood defences – structures whose primary objective is to block the pathway between the source loadings and the receptors which may be affected by flooding (see discussion in Chapter 2). This blockage only operates up to the design conditions for the flood defences.

Pure flood defences are typically found along (low-lying) coasts, rivers, lakes and artificial waterways. They include flood embankments (see section 6.2 – otherwise known as levees or dikes), flood walls (see Section 6.3), demountable and temporary flood defences (see Section 6.4). Flood defences may prevent flooding:

- From rivers (e.g. riverine earthen embankments).
- From the sea (e.g. coastal earthen embankments and tidal surge barriers).
- In intermediate situations (e.g. estuarine and/or lakeside earthen embankments).

Facilities installed for other purposes (see Section 6.5), where they cross the line of defence, will also have a flood defence function (e.g. ship locks, sluices and weirs).

However, other structures may assist in managing flood risk by:

- Temporarily detaining water upstream to prevent or reduce flooding downstream (e.g. dams and barriers across water systems or linked flood detention reservoirs) – see Section 6.6.
- Directing or diverting water (e.g. floodways, pumping systems) – see Section 6.7.
- Strengthening or protecting the main flood defence, either by reducing water levels (making room for the river) or by reducing the intensity of wave attack, including hard structures (e.g. offshore breakwaters) and/or nature-based components (e.g. dunes, beaches, salt marshes, mangroves, willow) – see Section 6.8.

This chapter focuses on flood defences for which it is possible to prevent or reduce damage or delay their failure through emergency responses.

For this reason, major structures such as storm-surge barriers are not discussed since:

- It is generally considered impossible to prevent or delay their failure through emergency responses.
- These are generally dedicated structures for which conventional emergency measures often do not apply.

6.1 Overview of flood defence systems

Flood defences generally function as a **system** (flood defence system), e.g. flood embankments, sluices, high lands etc. are connected linearly for protecting an area from flooding up to certain conditions. Such systems should be considered as chains that are only as strong as the weakest link, e.g. if a sluice in a flood defence system is breached, even though the flood embankments in the system are not breached, the purpose of flood defence system cannot be achieved. The integrity of the system is validated through its performance during flood events, assuming that any defects will be visible then.

Alignment of flood defences. In a fluvial environment, the first or main line of defence is usually parallel to the passing floods. The aim of the defence system is to channel water downstream of the river and to reduce the risk of flooding to nearby areas. Flood defences may be constructed along both banks with one defence set back from the river channel to incorporate part of the floodplain. In this case, during flood conditions, water will flow along both the river channel and the contained section of floodplain.

In the coastal environment, the defences are usually perpendicular to the incoming flow from the sea. The aim of the defence is to reduce the risk of crossing and overflowing of heavy seas and to prevent or mitigate wave overtopping.

Loadings. Flood defences are subject to varying forms of (dynamic) hydraulic loading (see Chapter 5), which may be derived from:

- The water level (including variations of the high-water level causing hydrostatic actions on the flood defence and influencing the internal hydraulics).
- The erosive potential currents and waves both on the waterside of the defence and on the landside if they result in overflow/overtopping.

Some hydraulic loads are very dependent on the bathymetrical and topographical conditions in front of the flood defence. Meandering channels, moving sandbanks and the presence of beaches in front of a flood defence have a significant effect on the loads derived from currents and waves.

Foundations. When understanding the weaknesses of each flood defence structure, it is crucial that the foundation soils for each structure should be understood considering geographical, geological and morphological characteristics. For example, if the foundation is located where there was once a riverbed or a small pond, the foundation soils may include a weak layer, and may be susceptible to backward erosion piping (see Chapter 9) when the water head difference between the waterside and the landside becomes large during floods.

Flood defence superiority. To predict those river flood defence sections where flood water is likely to first overflow when the flood discharge exceeds the design value, the following will need to be considered:

- Points of change in the longitudinal gradient of flood water level.
- Curvatures of flood flow.
- Local deposition of sediment raising riverbed levels e.g. at points of inflow from tributaries.

Designers of flood defence systems use these factors to adjust the positions at which first overtopping occurs to those where the

consequences are reduced or to locations where the defence is protected from erosion.

Life cycle of flood defences and link to emergency management. Flood defence structures typically go through a series of life cycles, i.e. planning – design – construction – operation and maintenance, and onwards. It is important to manage the structures based on these life cycles. The state of the flood defences should be also considered when responding during emergency flood situations. For example, in periods before reinforcement/ refurbishment/ renovation, there is an increased importance of well-organised emergency management since this is a stage/period in which the flood defence is not fully up to standards. Newly constructed earthen embankments may have unexpected weaknesses, so they need to be inspected with special care during floods for a certain period of time (e.g. 3 years) after construction. Also, repeated flooding events can have compounding effects that reduce the reliability of flood defences with time.

6.2 Flood embankments

6.2.1 Introduction

Flood embankments are often the principal component of a flood defence system. Flood embankments are raised, predominantly earth, man-made structures (also called levees, dikes, digues, or flood defence embankments) aiming at least to a certain degree to prevent floods entering the protected area. They are often constructed using locally available materials because of availability, reduced transport cost and ease of repair.

The usual hydraulic function of a flood embankments is to reduce the risk of inundation of an area by temporarily retaining water, keeping it out of the protected area to a defined water level, and to avoid flooding conditions within the defended area. However, flood embankments may also be used:

- As detention dams (see section 6.6) to provide a controlled release of water in a designated location that will minimise inundation downstream.
- To channel floodwater downstream or into a non-protected area to avoid inundation of the protected area.
- Alongside canals, where their function is to keep water contained within the confines of the canal or the land immediately next to it.

The height of a flood embankment is typically set by an anticipated water level, often based on historical trends. As development behind flood embankments increases, the embankment should either be widened and raised to improve its safety standard and mitigate flood risk or provision should be made for emergency measures to prevent failure.

Understanding the intrinsic structural and geotechnical properties of an existing flood embankment is fundamental to understanding its performance and reliability. Flood embankments range in quality from older 'non-engineered' structures composed of dredged material placed on poor foundation soils to well-constructed engineered embankments built using current standards on prepared and competent foundations. Many older flood embankments have been progressively raised and widened over the years as rural areas behind them became more urbanized and the soil structure inside their body may be unknown. The fact that such flood embankments may have stood for many years without being significantly loaded may create a false sense of security about the level of protection they will provide when tested to their design capacity. As demonstrated throughout history, breaching and overtopping of flood embankments and subsequent flooding of adjacent areas always remain a threat, regardless of a height of a flood embankment system and safety programmes.

To perform their desired function, flood embankments should retain flood water up to the design level. whilst providing:

- Protection against surface/external erosion on the waterside, the crown and possibly on the landside, including:

  - Erosion of the waterside slope (and resultant instability of the waterside slope through undermining of the foreshore or toe).
  - Erosion of the landside slope due to overflow and/or wave overtopping.
- Resistance to internal erosion.
- Mass stability of the constructed flood embankment, including stability of the foundation.

Details of the failure mechanisms against which embankments should be designed are given in Chapter 9.

Extensive stability analysis for these mechanisms is recommended when the consequences of flood embankment failure is higher but may become less important in cases where the consequences of failure risk are lower. For these cases, practical considerations such as type and ease of construction, maintenance, seepage and slope protection criteria control the selection of flood embankment widths and slopes. As a rule of thumb, embankments with wider crown width and/or gentler landside slope of flood embankment tend to have increased stability and overflow/ overtopping-resistance. These gentler characteristics also improve the living environment along rivers through land development on the flood embankment and provide evacuation sites when flooding occurs in the lowlands.

Flood embankments and their components do deteriorate over time due to various physical, chemical and biological mechanisms. The effects of deterioration are revealed by observable features or symptoms, such as cracks, fissures, depressions, bank caving, steep slopes, slides, slumps and lack of vegetation. However, there is no direct relationship between the symptoms and the mechanisms. One symptom can be linked to several mechanisms and one mechanism can lead to several observable features of symptoms. The appearance of a mechanism can be activated by a phenomenon initiator such as:

- An overload.
- A high water level or a rapid change in water level.
- Seepage.
- An abnormally raised flow or water.

A mechanism is a time-dependent process that affects a flood embankment component and involves a decline in the state of its structural properties. A mechanism can result in the deterioration and damage of one or more physical flood embankment components.

Good understanding of the flood embankment, its behaviour and its (relative) vulnerability for different failure mechanisms during flood conditions will assist in:

- Directing inspections on what specific features to look for (and where).
- The diagnosis of observed features (causes), i.e. the identification of the cause or nature of a defect or element of deterioration of a flood embankment (this relates to failure modes and processes).
- The prognosis of the performance of the flood embankment during potential future flood events, the need to take emergency measures (and which measures), such as external erosion protection measures, and infiltration reduction measures (See Chapter 6 of CIRIA (2013) for details).

6.2.2 Types of flood embankments

Numerous types and cross-sections of flood embankments exist, the geometry being dependent on the flood embankment type, loads, height, available land, earth fill material and foundation conditions. For example, seaside earthen embankments need to be designed to withstand strong external erosion forces, whereas for riverine earthen embankments geotechnical failure is often the primary factor in design. Some principal categories include (CIRIA, 2013):

- Homogeneous earth fill flood embankments (Figure 6.2).
- Zoned flood embankments (Fig. 6.3 and Fig. 6.4).

- Composite flood embankments (Fig. 6.5) – flood embankments including superstructures, structures on the waterside, structures inside, alternative constructions.

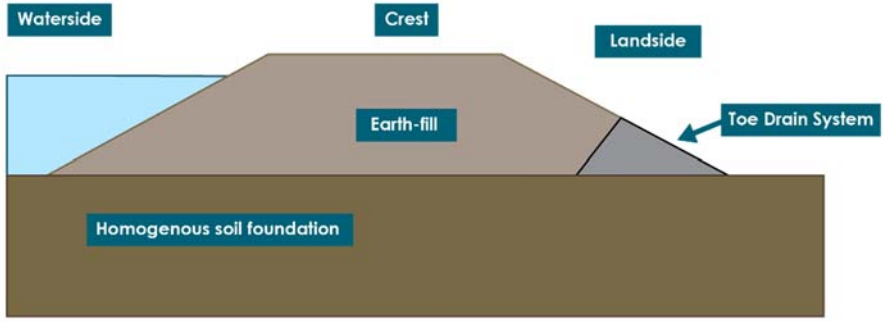

Figure 6.2: Homogeneous flood embankment with toe drain system (CIRIA 2013)

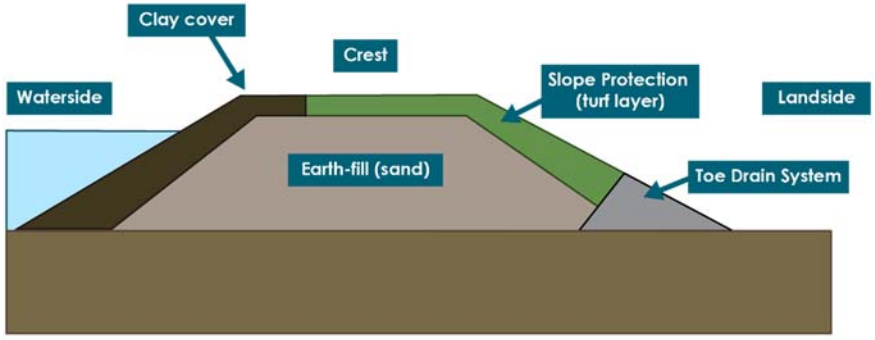

Figure 6.3: Zoned flood embankment with impermeable mask on homogeneous soil foundation (CIRIA 2013)

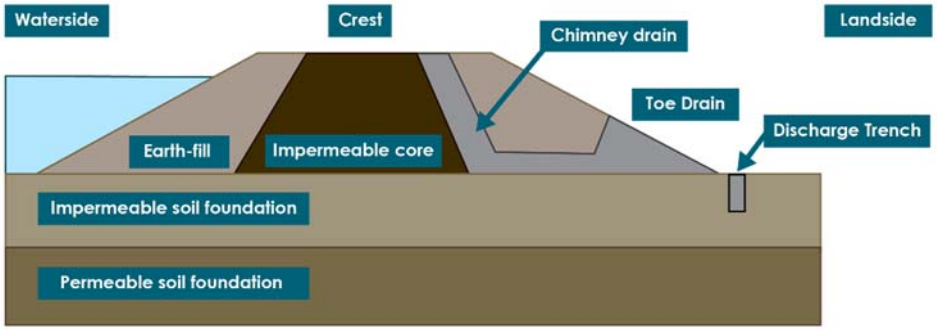

Figure 6.4: Zoned flood embankment with impermeable core on thin impermeable soil foundation (CIRIA 2013)

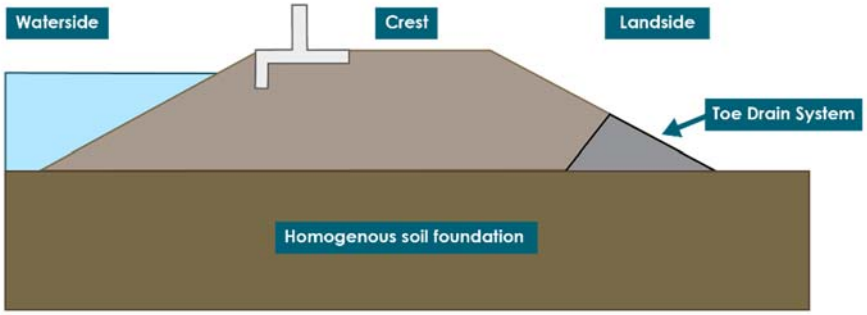

Figure 6.5: Concrete inverted T flood wall of flood embankment on homogeneous soil foundation (CIRIA 2013)

Modern flood embankments tend to have a well-defined structure and composition. By contrast, a historical/ heritage flood embankment tends to consist of more variable materials and more complex cross sections, composition is the result of many, often ill-documented, adaptations/ extensions/ repairs done in the past.

In a few cases, the main body of a flood embankment may consist of unusual materials, such as peat, glacial till, gravel or even rubble. However, most embankments make use of clay and its availability can be a significant factor influencing the selected cross-sectional configuration. Examples of such influences include:

- If there is an abundance of clay available nearby, a homogeneous cross section tends to be chosen. Conversely, if there is not enough clay available nearby, zoned flood embankment tends to be chosen.
- In countries where there are more dams than flood embankments or where there are many geotechnical issues, there is a tendency to choose zoned flood embankments with a clay core.
- When external/surface erosion and/or breach formation and growth by overflow/overtopping is a concern (for details see Chapter 9) and clay is not abundant, there is a tendency to choose a zoned flood embankment with a clay mask, especially on waterside slope.

Failure mechanisms (see Chapter 9) and associated countermeasures also influence the form of the selected cross section. Examples of such influences include the following:

- Where severe external/surface erosion and breach formation and growth by overflow/ overtopping is a concern, commonly chosen design options may be:
  - Hard revetments.
  - Less steep waterside slopes.
  - Berms.
- Where general piping and/or backward erosion piping is a concern, countermeasures may:
  - Include water penetration prevention through the waterside.
  - Berm construction to reduce the pore water pressure gradient across the flood embankment.
- Where landside mass instability is a concern:
  - The landside slope may be made gentler.
  - Berms or even sheet piles may be installed.
  - Drainage systems may be installed in the landside slope.
- When waterside slope instability is a concern, countermeasures may include water penetration prevention measures on the waterside.
- When liquefaction of foundation soil beneath a flood embankment is a concern, countermeasures may include sand compaction or soil replacement.
- When settlement is a concern, countermeasures may include additional earth fill mounds to offset the expected settlement.

6.2.3 Typical components of flood embankments

Flood embankments are arrangements of components that provide individual functions adapted to loads. Figure 6.6 illustrates these, although individual flood embankments may not have all the components shown.

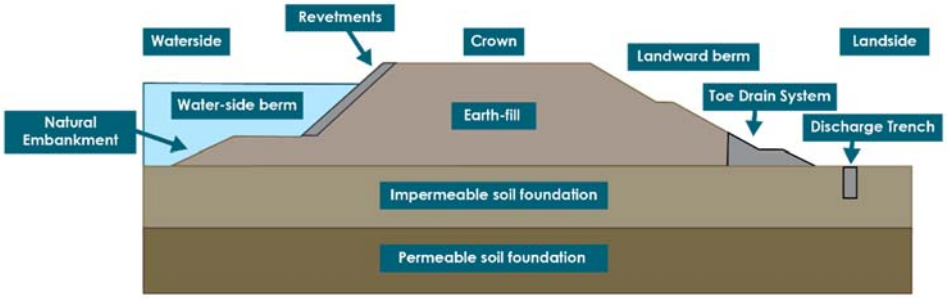

Figure 6.6: Individual components of a flood embankment (after CIRIA, 2013)

Components of flood embankments may include the following:

- Foundation soils, which interact with the flood embankment and can be complex, with highly variable strengths and permeabilities.
- Earth-fill, which is the main volumetric component of the flood embankment and is common to all types of flood embankments. The earth-fill usually consists of granular or cohesive soil materials (clay, silt, sand and/or gravel). In most cases, locally available materials are

used as earth-fill. If the earth-fill layer is sand or gravel and is too permeable, an impermeable core or mask may be added.

- The crown, which is the relatively flat, top surface of the flood embankment, and is often a nearly horizontal surface, with the highest point being known as the crest.
- Revetments, which act at the interface between the external environment and the flood embankment, on both the waterside and landside slopes. They serve to reduce the risks related to external erosion and uncontrolled infiltration of water into the body of the flood embankment.
- Berms, which are typically constructed as an extension of the flood embankment on one side of the flood defence system and may be composed of earth-fill materials or rock.
- Filter layers, which are zones of relatively permeable material within the flood embankment cross section between two layers or between earth-fill and drains. Filters often have two functions:
  - Drainage to relieve water pressures whilst retaining the flood embankment material.
  - Prevention of internal and contact erosion related to instability of the grain skeleton and/or soil interfaces.
- A drain system, which may be:
  - At the landside toe of the flood embankment (toe drain system),
  - Behind an impermeable core to collect the seepage through the flood embankment.
  - In the foundation soil at the flood embankment toe and/or to reduce internal pore pressure inside the flood embankment.

In addition to the above list, there are numerous auxiliary structures associated with flood embankments. Typical examples are spillways (Degoutte & Tourment, 2021), sheet pile walls, revetments and breakwaters. CIRIA (2013) provides further details.

6.2.4 Typical weak areas of flood embankments during high water events.

Transitions. A flood defence system generally includes a mixture of flood embankments and other structures such as floodwalls, gates, sluices, dams or other innovative construction in which the geometric configuration of the continuous line of defence differs. Numerous variations of transition types exist, such as:

- Between the soil embankment and surface revetment.
- Between the flood embankment and a flood defence structure constructed on the flood embankment.
- Between the flood embankment and a linear structure (e.g. pipes and culverts).
- Between the flood embankment and a non-linear structure (e.g. buildings, trees or bridge piers on the waterside slope).
- Between different types of revetments (soft versus hard) of a flood embankment.

Transitions between different geometric configurations or material compositions within the line of defence are important because they have a higher probability of failure during high water events than sections of a flood embankment that have a consistent cross section. Reasons for this weakness include discontinuities in shape and/or material constituents that concentrate of flows, erosion, and/or infiltration, either at the transition or immediately before or after it.

Depressions and rutting. Ruts are long stretches of depressions in the crown, toe, slopes or access ramps of flood embankments and range in size from a shallow depression of just a few centimetres caused by vehicular traffic or animal grazing, to potholes, which may be more than 0.30 m deep. When water ponds in ruts and depressions on a flood embankment's crown or access ramps, it may seep into the embankment and increase the moisture in the flood embankment. This increase in moisture may weaken the embankment and decrease stability, especially for loaded embankments during high water situations.

Settlement and subsidence both result in a lowering of the original ground elevation with consequent loss of the elevation of any overlying flood embankment or other flood defence structure. Settlement occurs from movement of the ground due to some type of loading, while subsidence occurs from movement of the ground due to loss of support in foundation. Both settlement and subsidence reduce the flood embankment's height, which reduces the design flood mitigation level. Localised lowering of the crest can also result in preferential overflow/overtopping and resulting erosion of the embankment.

Deterioration of grass cover. A continuous grass cover, on both waterside and landside slopes of a flood embankment provides protection against external erosion. Thus, parts of flood embankments with a deteriorated grass cover are relatively weak against external erosion by rainwater and overflowing/overtopping flood water.

6.2.5 Dry infrastructure embankment

Dry infrastructure embankments, such as road and railroad embankments, in protected areas, may be effective as secondary lines of defence along rivers or coasts. They may be parallel or perpendicular to the incoming floodwater. They may be effective as flood defences to reduce the risk of flooding in a more specific or restricted area. If they are to be effective as flood defences, any openings in the embankment, such as for crossing roads, must have temporary closures installed in advance of the flood.

Such infrastructure embankments may also be useful as food detention structures (see Section 6.6) when they act to:

- Confine flooding to a specific and defined area (flood detention reservoir).
- Detain flood water in one sub area, delaying flooding in another sub area.

6.3 Flood walls

A flood wall is a vertical barrier designed to temporarily contain a river or other body of water. Typically, water levels in such water bodies vary in time, rising significantly during seasonal or extreme weather events. Flood walls are mainly installed in locations where space is scarce, such as urban environments or where the construction of a flood embankment is not feasible. Flood walls may be gravity structures (see Figure 6.7), T walls or I walls. They may be constructed of mass concrete, reinforced concrete or piles (typically steel sheet piles). Some additional details are given in CIRIA (2013).

Flood walls are sometimes added to the crest of a flood embankment when defence raising is required but there is insufficient space to widen the flood embankment in order to raise it.

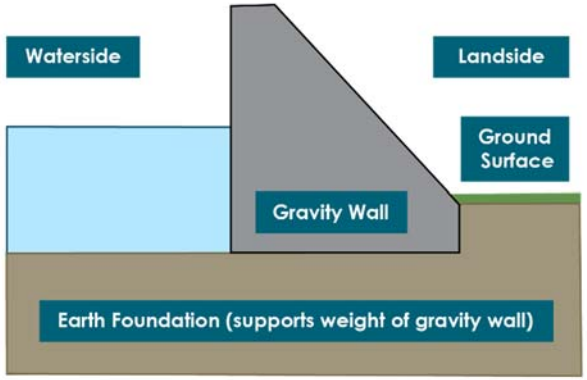

Figure 6.7: Gravity flood wall (CIRIA, 2013)

Whilst the main focus of the design of flood walls is on their structural design and on avoiding mass instability, attention also has to be paid to avoiding erosion of the land or foundations on either side of the wall to avoid undermining or destabilisation.

6.4 Demountable and temporary defences

Temporary defences are any flood defences which are installed in the pre-emptive stages of an expected flood incident, and removed after the threat has passed, so that there is no defence present when it is not needed. Whilst this definition includes demountable defences, this handbook makes a distinction as follows:

- **Temporary defences** are mobile defences which are installed during flood conditions, and removed in their entirety during non-flood conditions. They have no fixed foundation other than the natural or manmade surface upon which they are placed. Examples of temporary defences include pallet barriers, sandbags, large 'dumpy' bags, water-filled barriers.
- **Demountable defences** (see for example Figure 6.8) are defences which either:
  - Have permanent in-situ structural foundations below the ground, and removable structural components above the ground, and some form of permanent connecting mechanism at ground level, or
  - Have permanent defences immediately adjacent which are used for structural support, and a permanent connecting mechanism to those adjacent defences.

During flood conditions, the structural components are connected to the foundations and/or the adjacent defences ("mounted"). When the flood has passed, the structural components are removed ("demounted"), but the foundations and connectors remain in place. Examples of demountable defences include stoplogs, screw-in pillars and clip-on panels.

Figure 6.8: Demountable stoplog barriers in Bewdley, UK (courtesy: Environment Agency)

Temporary and demountable defences are generally used when a permanent linear defence is too obstructive. Possible objections to a permanent defence include:

- It might block an access route that is needed for pedestrians or vehicles.
- It might divide an area that would be better left connected.
- It might obstruct lines of sight that are beneficial to the local landscape, often including the view of the river/coast itself.

The main advantage to using these types of defences is that they are absent when they are not needed, addressing all the objections above. However, they come with a range of risks (described below), which are

often considered disadvantageous to the authorities responsible for mobilising and demobilising them. For this reason, common practice is for sections of temporary and demountable defences to be kept as small as possible, connecting into permanent linear defences as near as is practical. For example:

- Horizontally: If a permanent defence would block a road, a typical design would use permanent defences as close to the road as possible, and then use a temporary or demountable section that only spans the vehicle carriageways and the pedestrian walkways. If there is a central reservation, it is sometimes beneficial to use a very short permanent defence there, as its splits a long temporary/demountable section into two shorter ones.
- Vertically: The visual detriment of a permanent defence from the top half of, say a 2-metre high, wall can be overcome by use of a 1-metre high permanent wall surmounted by a additional 1-metre demountable barrier.

Other advantages of using these temporary and demountable defences include:

- **Both** are kept in storage when not in use, protecting them from the weather and other causes of deterioration.
- **Both** demonstrate consideration of local needs beyond flood protection, which may help with gaining stakeholder acceptance, and obtaining any necessary approvals from regulatory authorities.
- **Both** have the potential for a single unit to be used in more than one place, if there is an acceptably low risk that flood conditions could arise in those places at the same time. For demountable defences, the connectors and dimensions must be compatible.
- It is possible to deploy **temporary defences** to any site with suitable ground conditions, giving them the flexibility to be used at short notice, even at sites where they have not been considered before. Although ground conditions at an 'ad-hoc' site may be suitable for temporary defences to be successfully installed, the use of unassessed or untested ground creates an increased likelihood of failure upon loading, which in turn introduces new risks to safety. Therefore, operators should consider the balance of risks reduced vs. risks increased.
- **Demountable defences** are particularly common when defences are needed for an individual property, such as a home or a business, as they present a popular compromise between the avoidance of a disruptive permanent defence, and the ease of installation when a defence is needed.

Disadvantages include:

- High structural risks, as the designs of **both** are often less stable than permanent defences, so that they can be more mobile. There are also structural risks that arise from changing site conditions – for example, grassy or asphalt surface is replaced with something like gravel, it may no longer provide adequate friction to stop a temporary defence from sliding.
- Due to their mobile nature, **both** carry a risk of being damaged whilst erected, dismantled or whilst in transit.
- **Demountable defences** carry the risk of being inoperable when needed. Connectors may be damaged or unusable. For example, sockets for screw-in pillars could be full of dirt or ice.
- **Both** are reliant upon operators attending the site to install the defences. This introduces multiple operational risks:
  - Operators may be unable to attend due to resource constraints (likely in the build-up to a forecast flood event) or inability to access the site (e.g. nearby roads flooded).
  - Conversely, if operators *are* able to attend the site, it may draw valuable resources away from flood-incident response activities elsewhere.
  - There are risks to safety when installing the defences, particularly in the stormy conditions that are likely to be present when flood flows are expected. Operational staff may also need to install the defences during nighttime hours.

- The successful use of **both** is dependent upon accurate and timely weather monitoring and forecasting. If the flood defence management organisation does not foresee flood conditions sufficiently in advance, then it is likely that it will fail to mobilise the defences in time. This could lead to avoidable flooding, and both legal and reputational risks to the organisation.
- Whilst the initial cost in creating temporary and demountable defences may be low, **both** come with high ongoing costs for storage, maintenance, deployment, supervision of installed defences, and replacement parts.

Given all these risks, organisations that operate temporary and/or demountable defences are advised to make contingency arrangements for situations where the defences are not installed when they are needed, or are unable to tolerate the loads placed upon them.

Both temporary and demountable defences need to be tested regularly to ensure that they are still operable and in adequate condition, and the operational staff responsible for installing them are advised to conduct regularly exercises to ensure that they remain skilled and confident in their operation. For demountable defences, it is prudent to carry out exercises on-site if possible.

6.5 Ancillary structures in flood defences

6.5.1 Introduction

When flood embankments are constructed as part of a flood defence system, other functions such as transport, water use, and drainage, may be impeded. Therefore, numerous types of structures are needed within the line of defence that both maintain these functions as well as the flood defence function along rivers (Figure 6.9), canals, estuaries, and adjacent to a lake or sea. The functions of such structures vary but essentially, the basic functionality of these structures is either to:

1. Let water, vessels or vehicles pass through, such as:
   a. Excess water that needs to be drained from an area after rainfall.
   b. Tidal water needing to enter an inlet.
   c. Ships needing to move from one water body to another.
   d. Vehicles needing to pass from one side of the embankment to another.
2. To act as a water barrier:
   a. To retain water in a waterbody so ships have enough draught to sail.
   b. To function as a flood barrier.

Figure 6.9: A sluice in Upper Kisogawa-River (courtesy: Upper Kisogawa River office, MLIT)

Corresponding to these two functions, the ancillary structure is part of two systems: a flood defence system and a transport system. Therefore, their design and operation need to consider the requirements of both systems

in the context of the whole emergency management situation. Consider the following examples:

- If the waterbody behind the structure (on the protected side) has a large area for storage, some overtopping or other excess water will not significantly impact on the flood situation behind the structure. This implies that design and operational requirements can be less strict.
- High winds, heavy rain and landslides may restrict the ability to reach the structure during emergency response and affect the safety of emergency staff. Access may be impeded whether this is by water or land.

In general, it will always be essential to have a thorough understanding of the (extreme) water levels, discharges and morphology of both water systems, as well as their forecasted values. Examples are:

- Adequate forecasting of the maximum water level which will occur;
- The degree to which the water level of the protected waterbody can rise without serious consequences (flooding, stability of structures, salt intrusion etc.).
- The water can flow across the structure or adjacent defences and land without the risk of erosion and resultant weakening of the structure, especially at the interface between the structure and the adjoining land or flood embankment.

In the following more information is given about the functionality of different structures and the implications when using the structure as a flood barrier.

6.5.2 Lock

A Lock is a structure allowing ships to move between water bodies with different water levels. The difference in water level can be caused by a tidal difference (sea lock) or other reasons (normal lock). Thus the primary function of a lock is to transport a ship vertically, but it often also has the following additional functions:

- Draining rainwater from a river or canal on one side of the lock.
- Making it possible for road traffic to cross the waterway.
- Functioning as a flood barrier.

The vertical movement of ships is achieved in a lock chamber, which can be closed by horizontally moving doors or vertical moving doors. The vertical movement of the ship is then made possible by a valve-operated levelling system which moves water in or out of the lock chamber.

Figure 6.10: Arakawa River Lock Gate in Tokyo (Source: Arakawa-Karyu River Office, MLIT)

The flood emergency plan must provide information on **closing the lock doors** to prevent flooding, e.g.:

- Are there specific flood door(s) to be closed to prevent flooding either of the area or of features within the lock system? Conversely, which doors can be left open without severe consequences? In terms of risk, it is important to distinguish between locks which are normally open (and only closed on demand) and the opposite: locks which are normally closed and only open on demand.

- Are there specific conditions which are necessary for the doors and associated valves to be closed? Often doors and valves can only be closed when the water level difference is not more than a particular height. If this height is exceeded during the onset of the flood, are there different ways to close them?

6.5.3 Control lock – what is the difference for emergency management?

The main difference between a normal lock and a control lock is that **the main function of a control lock is to regulate the water level**. Yet, most of the time there is also shipping in which case it should be possible for ships to cross.

Sometimes there is one structure which can be opened so water and ships can pass. During flood conditions the structure is closed preventing water or ships to pass. In other situations, next to the control lock there is a normal lock which makes it possible for ships to pass when the control lock is closed.

Figure 6.11: A movable weir to regulate water levels in the River Nederrijn, The Netherlands (Source: Rijkswaterstaat)

In case of a flood emergency the control lock should always be closed. This is the only way to stop the water from flowing. As this should be normal operational procedure, the key point is to ensure the actual closure of the control lock.

6.5.4 Weir

A weir is a construction in a waterway (river or canal) to keep a certain water level upstream. This is mainly for nautical purposes. *In case of a flood emergency* the weir must be opened *to provide capacity for the high water discharge*. When the weir is closed the ships may pass through a separate lock.

Figure 6.12: Youhai weir in Kumamoto Prefecture, Japan (Courtesy PWRI)

6.6 Flood detention structures (dams)

For the purposes of this handbook, dams or flood detention structures are normally built perpendicularly across a watercourse (whether wet or dry during normal conditions). Their purpose is to detain (store) water on the upstream side to reduce the risk of flooding to receptors on the downstream side. This makes them distinct from flood defences which are built parallel to a watercourse or to a coastline for the purposes of keeping water out of the protected area. However, some flood detention areas are created to one side of the water course and connected to it via pipes or channels with necessary control features in them to move water in and out of the detention area.

Coastal barriers - flood retention or flood detention structures?

Coastal barriers are flood defences retaining flood water from entering the protected coastal area rather than to detain water like dams. Whilst, like many dams, they are built perpendicularly across a watercourse or estuary, like a dam, they are also parallel to the main line of the coast, like a flood defence, and they usually connect to coastal flood defences on either side of the watercourse/estuary.

It is worth noting, however, that when a coastal barrier is closed, it also has the effect of acting like a dam to water flowing down the watercourse. At coastal locations, this is a detrimental effect as the receptors at risk are inevitably on the upstream side. The risk can be managed by ensuring that the barrier is only closed when the sea level is higher than the river level (when the flow direction would be upstream), by pumping over/ around the barrier when it is closed, or by using pressure-driven valve arrangements, such as flap valves or pointing gates, to give fluvial water an escape route if the barrier is closed while the river level is higher than the sea level.

Dams are typically large constructions which allow for a large water head across the structure. Other than flood risk management, a dam may be constructed for multiple purposes including hydropower, water supply and amenity. On the upstream side of the dam there is a large lake of temporarily or permanently detained water normally called a reservoir.

Figure 6.13: Kuzuryuu dam, a rock-fill dam, for flood control and power generation in Japan (Courtesy: PWRI)

When to use a dam to detain water for flood risk reduction

The feasibility of constructing a dam is heavily reliant on topography. The ideal combination of features is:

- Steep valley slopes either side of the river, as the steepness of the valley will dictate its width, which in turn will dictate the length of the dam needed to seal it. In large, flat areas, low dams may still need to be extremely wide to tie into natural ground. This makes them costly and disruptive to build, which is why countries like the Netherlands have relatively few large dams.
- A shallow valley slope at the upstream side of the potential dam location, as this dictates the volume of water that the dam can detain in its reservoir. Two dams of similar height may hold vastly different volumes of water, depending on the shape of the upstream catchment.

It is ironic that the ideal topography for a dam is practically the opposite to the ideal topography for a reservoir, and yet these seemingly contrary landscapes coexist more often than one might expect. Common valley features like canyons, ravines or simple topographical bottlenecks, form

natural pinch points that bring together a narrow width for a dam to span, with open space upstream for the retention of water. These features are formed by the geological influence of flowing water, so the natural processes of long-term fluvial erosion helpfully favour the formation of the topography needed to build dams.

Where the conditions permitting a dam to be constructed across a watercourse do not exist, the topography may still permit a flood detention reservoir to be constructed away from the main river. In this case, diversion arrangements will be required to move excess water from the river to the storage area and to return the water to the river when the high discharges in the river have subsided.

6.6.1 Types of dams and their components

Dams built for the purposes of flood detention are usually earth embankments made of compacted soil, often excavated from the local area, and usually covered in grass. Alternatives to earth sometimes used include hardfill/rockfill and cemented materials.

Dams are also often made of concrete, although this is less common in dams built purely for flood detention purposes, Flood reservoirs are usually kept empty, whereas concrete is better suited to reservoirs that are usually kept full, such as those for water supply or hydropower reservoirs or artificial recreational lakes. Nonetheless, concrete dams can be built and used partly for flood defence, either in a 'gravity' formation where the structural stability is generated through the shear mass of material, or in a 'buttress' formation where the stability is generated through triangular shaped walls on the downstream side which prop up a large concrete wall (see examples in Figure 6.14). Concrete dams can also be built in an arch formation, like the Hoover Dam in the USA, but this formation is generally unsuitable for flood detention dams.

Figure 6.14: A gravity dam (Claerwen) and a buttress dam (Stwlan), both in Wales (Source: British Dam Society, 2023)

Typical main components of an embankment dam include the following (see Figure 6.15):

- Central core of a low-permeability soil, usually clay, or an impermeable material like concrete. The core is the key component of a dam, so much so that it is possible to say that the other components are secondary, in that they are used to support the core.
- Shoulders of other soils buttressing the core on the upstream and downstream sides of the core and giving it structural stability. The soils used vary according to what is available, and sometimes multiple soil types are used, laid adjacent to each other in a 'zoned' formation. The soils are compacted when placed to maximise their density, which in turn increases their frictional strength, and reduces the extent to which they will settle over time. They are constructed in a shallow-sloped trapezoidal shape, forming a bulk landmass that can support the weight of water behind it without sliding, and which will not slip under its own self-weight.
- Drainage systems. Dams with a soil core often include drainage systems on the downstream side of the core, consisting of a thin layer of high-permeability material, like sand or small gravel. This serves two purposes:
  1. It ensures that any water seeping through the core can escape, without taking the soil from the core with it. It filters that water from the soil, ensuring that soil stays where it is.

2. It controls the route of that water, directing it to a point on the downstream side where it can be safely released. This reduces the risk of water seeping through the whole dam and egressing on the downstream face, where it could take soil from the shoulder with it. If that seepage were to continue, it could trigger a 'backwards erosion piping' (see Chapter 9) issue, eventually leading to erosion of the core, or settlement of the whole structure.

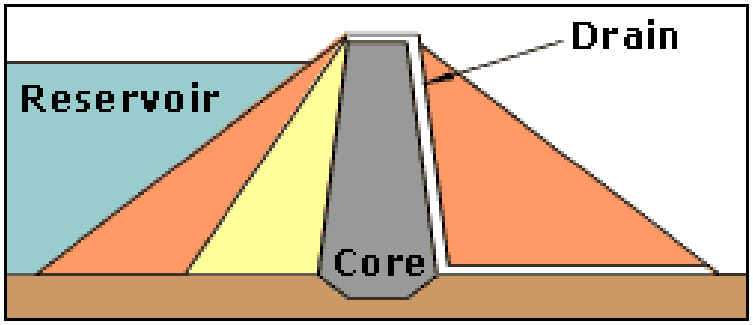

Figure 6.15: Typical cross-section of an earth embankment dam (source: British Dam Society, 2023)

6.6.2 How a dam works to reduce flood risk downstream

During non-flood conditions, the watercourse flows through the dam using a culvert/ tunnel, typically a concrete conduit, made big enough to convey the normal volume of water.

During flood events, the flow through the dam is restricted, either in a passive way by the size of the culvert/ tunnel or in an active way by some kind of mechanical throttle, such as a gate. Because the flow is restricted, the river level downstream does not rise as fast or as high as it would have done if left unrestricted. This reduced river level means that flooding is reduced or avoided entirely. However, the restricted flow also means that the volume of water flowing through the dam is lower than the flow approaching it from upstream. This creates a surplus, causing water to accumulate immediately upstream of the restriction. The dam ensures that this water is stored safely, creating a reservoir (see example in Figure 6.16).

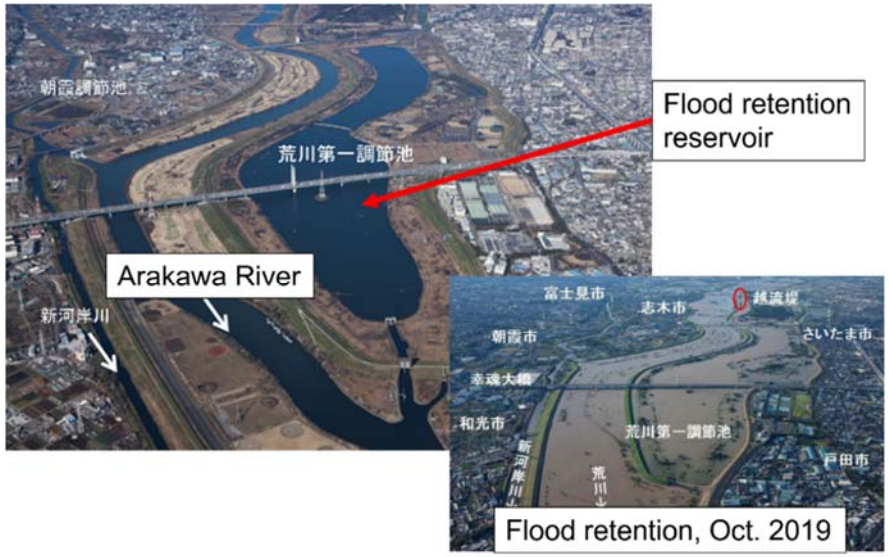

Figure 6.16: Arakawa River flood retention reservoir (courtesy: MLIT)

As the flood passes and the flow from upstream reduces, the stored water can be safely released, emptying the reservoir until non-flood conditions are restored. As the reservoir empties, river levels downstream are higher than they would otherwise be, but lower than they were during the peak of the flood.

In very large floods, the reservoir may rise to the point where it overflows the dam. For this reason, dams have spillways which act like the overflow on a bathtub. They take the surplus water from the top of the dam and route it through an artificial channel, usually lined with concrete or masonry, back the channel on the downstream side. At this point, the dam has done all it can and is less effective in reducing flood risk downstream as it is allowing more water to escape, but the spillway

ensures that the reservoir doesn't overtop onto the dam's soil materials, which would create a high risk of rapid erosion and potential dam failure.

6.6.3 Dam emergency response situations and measures.

In most flood emergencies, the operation of reservoirs detained by dams play an important role in flood emergency response. This includes their operation before, during and after flooding. In such cases, the approach to both regular detention and particularly emergency detention become critical in discussions between the engineers and the decision makers before and during emergency response. The approach adopted should be evaluated after each flood.

Where the reservoir has multiple purposes, there are often difficult decisions in the pre-flood season of the year. Whilst for flood risk management purposes the water levels in such reservoirs should be kept as low as possible, most other purposes for the reservoir require water levels to be kept high. Good seasonal forecasting combined with scenario modelling can help to optimise the required water levels in this pre-flood season

During flood emergencies some additional responses may be required:

- If the flood inflow exceeds the design scale of the flood detention reservoir, the emergency response should be selected based on the characteristics of each facility, e.g. emergency operation of a drain gate or discharge syphon.
- If a dam does fail, there will be rapid serious consequences downstream because of the sudden water level rise. Hence if a dam is at risk of failure and if it is ascertained that there is enough time for evacuation, the best option is probably to get as many people as possible away from areas that will be affected. If time for evacuation is short, staying at home or evacuating to a local safe place may be an option (depending on time available and the probability of homes being flooded or even destroyed).

6.7 Flood diversion structures

There are auxiliary flood risk management structures such as floodways, flood diversion tunnels, and pumping stations for drainage that help to reduce flood risk by diverting flood water and hence lowering flood water levels in critical areas.

A **floodway** is a designated path (see Figure 6.17) for diverting excess floodwater when river levels exceed a specific threshold. The operation of the diversion lowers the flood water level in the river. An emergency response for a floodway might be needed if the discharge in the floodway exceeds the design value. The specific emergency response should be selected based on the characteristics of each facility. An example response would be temporary raising of flood embankments alongside the floodway.

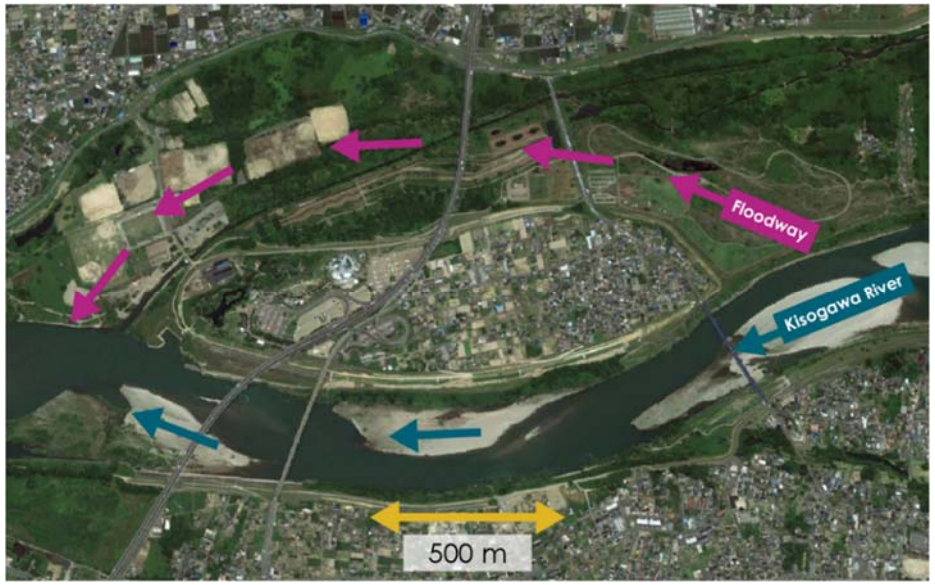

Figure 6.17: Floodway in Upper Kisogawa River (added to aerial photograph by Geospatial Information Authority of Japan)

A **flood diversion tunnel** is an underground passage (see Figure 6.18) used to divert excess floodwater when river levels exceed a threshold value. The operation of the tunnel lowers the flood water level in the river. An emergency response might be needed if the flood discharge exceeds the design value. The specific emergency response should be selected based on the characteristics of each facility. An example response would be closing the inflow gate to the tunnel.

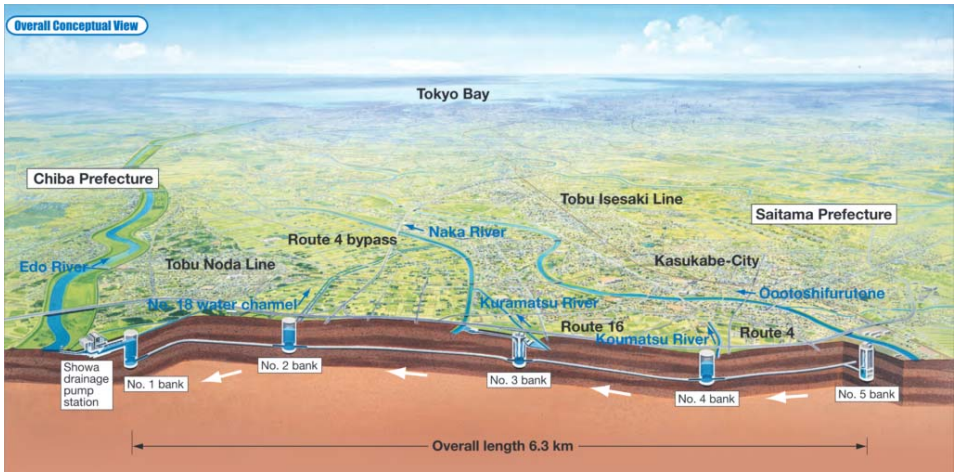

Figure 6.18: Flood diversion tunnels in Tokyo Metropolitan Area (Courtesy: Edogawa River office, MLIT)

A **drainage pumping station** (see Figure 6.19) extracts water from protected areas when gravity drainage is impossible because of the high water level in the river into which the water normally flows. If the water level of the river to which the drainage is being discharged exceeds the design water level, a possible emergency response would be stop pumping. However, if the water level around the pumping station in the protected area rises to a dangerous level, the emergency response must ensure the safety of pump operators, and ensure they can be evacuated if needed.

Figure 6.19: Pumping station for drainage in Upper Kisogawa-River (courtesy: Upper Kisogawa River office, MLIT)

6.8 Load reduction systems for flood defences

Some features may be included in a flood risk management system to reduce the loads (water levels and/or waves) on flood defence structures, although these are not part of the flood defence structures as such. Examples of these features are wave-reducing salt marshes/ forelands, load-reducing vegetation (trees, mangroves) along rivers, estuaries or coasts, as well as sand dunes. Most of these features do not require emergency management.

Strips of **woody vegetation** (see example in Figure 6.20) can wave and current loads on flood defences by dissipating wave energy and diverting flows, although care must be taken to avoid enhanced erosion outside the area with the vegetation. An example of this is mangrove belts planted along a coastline which can dissipate the energy of incoming waves and thereby reduce the loading on coastal flood defences. Wide coastal salt marshes and forelands can have a similar effect to mangrove belts.

Beaches and dunes are naturally occurring, non-rigid shore protection features created through the combined action of sand, wind, waves, currents and vegetation. In a similar way as coastal flood embankments, beaches and dunes reduce the risk of inundation to coastal property during wave action and storm surges. They may provide initial protection to man-made flood defences or provide the entire flood defence.

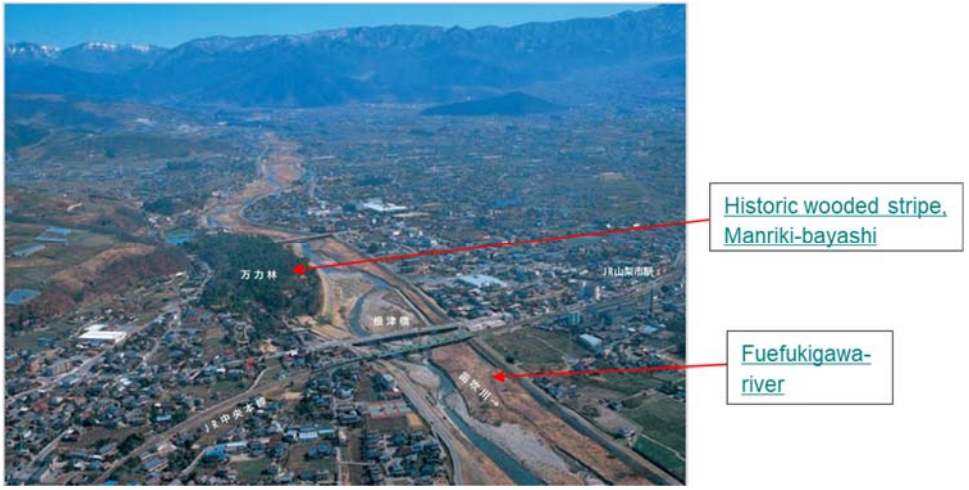

Figure 6.20: Historic wooded stripe (Manriki-bayashi) for flood damage mitigation bordering Fuefukigawa-River(courtesy: Koufu river and national highway office, MLIT)

River restoration is a variety of modifications of river channels and adjacent riparian zones and floodplains, and of the water, sediment, and solute inputs to rivers. These modifications (see example in Figure 6.21) share the goal of improving hydrologic, geomorphic, and/or ecological processes within a degraded watershed and replacing lost, damaged, or compromised elements of the natural system (Wohl, et al 2015). By increasing the capacity of the water course during high water conditions, river restoration can reduce lower peak flood water levels and/or reduce flow velocity around flood defence structures and thereby mitigate flood defence system failures.

6.9 References

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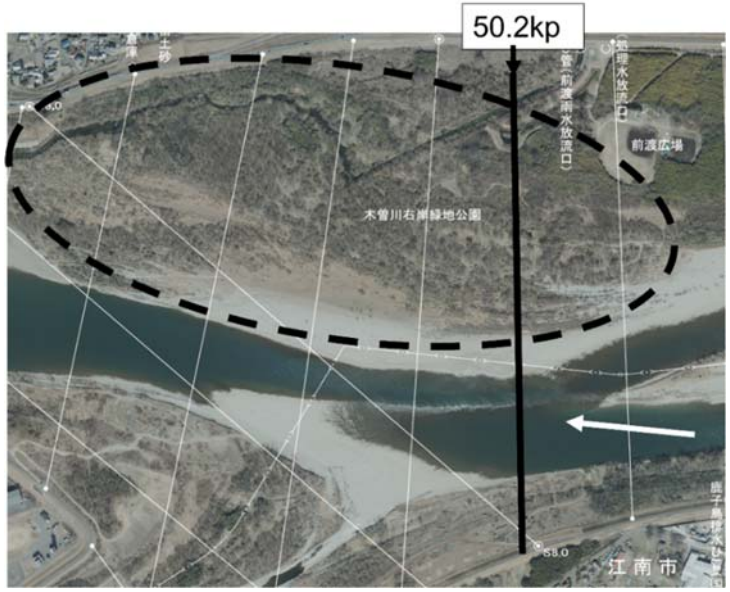
(a)



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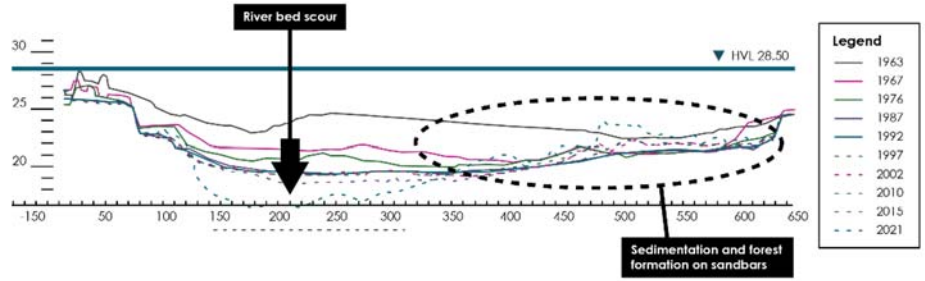

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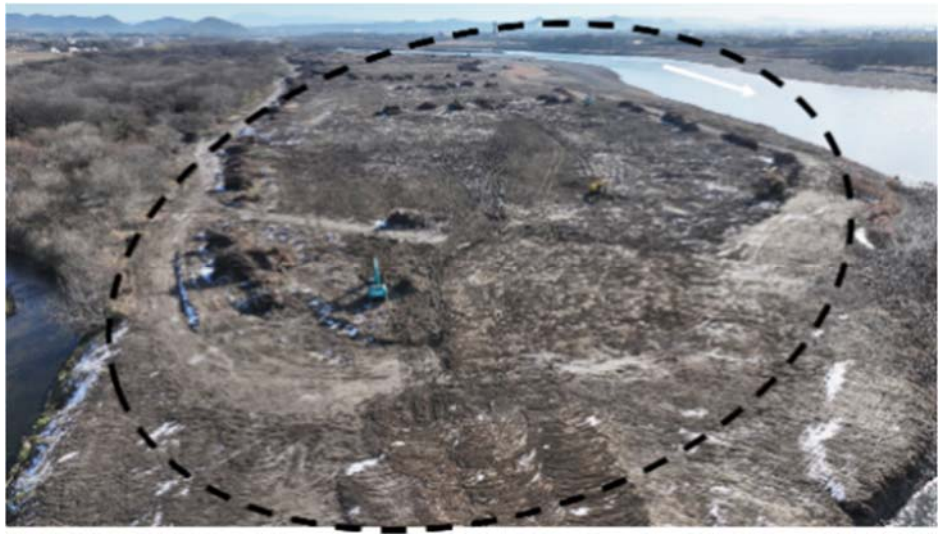

(d)

Figure 6.21: River restoration work in Upper Kisogawa River
(a) aerial photo in 1961 (Source: Geospatial Authority of Japan)
(b) aerial photo of the same location in 2021
(c) changes in cross-sectional shape at 50.2kp
(d) cutting down trees on the sandbar in 2024.
(courtesy: Upper Kisogawa River office, MLIT)

CHAPTER 7

Communicating for emergency management

Key messages:

- **Build a reactive risk communication framework**
- **Navigate the emergency vortex**
- **Master professional communication**
- **Cultivate open communication**

Figure 7.1: Structure of the handbook

Other places to find information on the topics in this chapter

Chapter 2: governance standards that are essential for emergency response, including effective information transfer and communication

Chapter 3: basic principles of preparedness that guide the identification of communication needs in different flood scenarios

Chapter 4: information on the Joint Decision Model and an example of flood warning service.

Chapter 5: data and information to be communicated during an emergency

Chapter 6: flood defence types to be considered in emergency response and communication planning

Chapters 8 through 12: details of the process and what needs to be communicated when and by whom to ensure effective implementation of emergency measures

Chapter 13: health, safety, and wellbeing considerations to support effective communication planning

Chapter 15: benefits of joint training exercises, skills- and lessons-learnt-sharing in future flood response and communication planning

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Note:

The Reader is kindly requested to take note of the Disclaimer on page ii of this handbook.

Chapter title page photograph:

Communication during an emergency (courtesy: USACE)

Key messages:

- **Build a reactive risk communication framework.** Professionals are equipped with tools and frameworks to proactively communicate potential risks. This includes identifying hazards, crafting clear messages, choosing appropriate channels, and fostering trust with stakeholders. The framework should account for the crucial difference between risk communication (proactive) and communication for emergency management (reactive).
- **Navigate the emergency vortex.** A step-by-step roadmap guides professionals through communication for emergency management. It highlights forming a response team, gathering accurate information, delivering consistent messages, addressing misinformation, and prioritizing recovery.
- **Master professional communication.** Effective communication skills are crucial during both risk and emergency scenarios. The chapter focuses on clear and concise messaging, active listening, tailoring communication to audiences, maintaining professionalism, and using nonverbal techniques effectively.
- **Cultivate open communication.** The importance of a culture of open communication within an organization is stressed. This involves encouraging two-way communication, providing avenues for reporting concerns, conducting regular drills, and building trust across all levels.

The sections of this chapter discuss the following:

- Section 7.1 – the role of communication in emergency management of flood defences
- Section 7.2 - communication between tactical, operational and strategic levels of emergency management
- Section 7.3 – coordination of information and collaboration between professionals involved in emergency management
- Section 7.4 – media relations during an emergency, including training of media spokespersons
- Section 7.5 – communications with the public, especially those who are less well-served
- Section 7.6 – communications between international organisations for mutual learning

7.1 Role of communication in emergency management

Well-planned and effective communication for emergency management is critical to ensure a robust response to an emergency and can deliver a significant saving in lives and resources. Public awareness is a huge part of the risk reduction and prevention of any disaster including floods. In the United States, every $1 invested in disaster mitigation by three federal agencies saves US society $6 (National Institute of Building Sciences, 2019).

Communication for emergency management to support flood risk reduction is at the heart of the emergency management cycle. It may be defined simply as collecting, processing, and disseminating information to address an emergency (Coombs & Holladay, 2010). It should be part of the professional routine of the Flood Defence Managers and can be provided at little or no additional cost. Important elements of communication that increase the effectiveness of emergency management and response include:

- Communication between professionals within organisations, sharing information and clearly communicating instructions about the emergency with colleagues so that they can fulfil their roles and responsibilities and implement any decisions.
- Communications between professional partners who need information to be able to play their role in an emergency.
- Communication with community members including regular meetings or providing information on flood risks and preventive behaviour. Such communication is not just to facilitate response and recovery after a flood emergency, but also to raise public awareness and enable communities to become more resilient to the impacts of flooding. It is one of the most efficient tools of public affairs and helps to build and maintain an organization's favourable reputation, especially during emergencies when the public need to trust an organisation's messaging regarding the action they are advised to follow.
- Establishment of a communication plan that outlines roles, responsibilities, and communication channels for all responders. The plan should include backup communication methods in case primary channels are compromised.
- Development and distribution of an emergency notification organizational chart. The purpose of the chart is to establish who will be notified by whom and in what priority for a given set of circumstances. At minimum, the chart should include names and essential contact information (e.g., home, office, and mobile numbers). Apart from internal organizational contact information, flood defence operators should establish a directory including telephone numbers for the area's emergency operations centre, local contractors and vendors who can assist, vendors, police and fire departments, relief agencies, volunteer agencies – basically all entities that may play a role during a flood response.

Each phase of the Emergency Management Cycle (see Chapter 2) involves collecting and spreading information with the main goal of minimizing possible damage and reducing risk to life.

Communication during the preparedness phase is called pre-emergency or risk communication and may be viewed as a dialogue between organizations and stakeholders to learn about the risks and how they can reduce those risks (Coombs & Holladay, 2015). During this period, existing flood risks are being understood and safety rules are being developed, embedded and then translated to the public and other professional partners involved in flood defence management to educate them, raise awareness and improve preparedness as well as for community engagement in prevention and preparedness. Preparedness phase communication elements are elaborated more in Chapters 3 and 8.

Communication during the response phase includes the following:

- gathering information about the hazards of a flood and sharing information about safety rules or evacuation routes required to respond to the flood emergency.
- obtaining and providing specific information about damage, or suffering people, communities or organizations to enable the development or implementation of the recovery plan after the flood.

7.2 Communication at strategic, tactical, and operational levels

Regular and well-structured communication at all levels is critical in the run-up to, during and after an emergency. Organisations should operate a command structure model (see example in Figure 7.2) that enables the flow of information from the strategic level to the tactical level and to the operational level:

- Strategic commanders are responsible for setting the strategic direction of the response. This should include the guiding principles of

how the organisations involved will work, focussing on the highest risk issues (such as risk to life) and should provide the tactical commanders clarity on their focus and tasks.

- Tactical commanders are responsible for using the strategic objectives to develop the tactical plan for the activities to respond to the emergency.
- Operational commanders are responsible for operational delivery and response of the tactical plan on the ground e.g. at the site of the emergency(s).

The communication at and between strategic, tactical, and operational levels should be included in the planning of any additional flood defence or other elements of response that need to be prepared (see Chapter 3). Failure to identify relevant strategic objectives risks tactical commanders not developing robust tactical plans and may limit the operational response.

The different levels of command must make sure that they focus on their respective level of involvement. Each level should avoid straying into the work of another level (e.g. a strategic commander becoming involved in the work of a tactical commander) as it risks distracting commanders from their respective areas of command and focus. For this reason, commanders should challenge themselves on their areas of focus to ensure that their work remains at the correct command level. To help commanders to keep their focus, some organisations have implemented a 'Command Support Manager' or critical observer who acts as a critical friend. This individual also helps to ensure that commanders use relevant plans and implement improvements identified from previous emergencies.

Figure 7.2: UK Government command structure example for a complex emergency

UK Joint Emergency Services Interoperability Programme (JESIP) command structure

The UK Government's document on the Concept of Operations (Cabinet Office, 2013) provides a recommended command structure for an emergency (see Figure 7.3) that can be followed. Further information on the structure of multi-agency joint working is available from JESIP (n.d.). The recommended command structure offers flexibility and can be applied to any type of emergency or operation (see the example in Figure 7.2). More information on the Joint Decision Model used during the emergency is given as an example in Chapter 4.

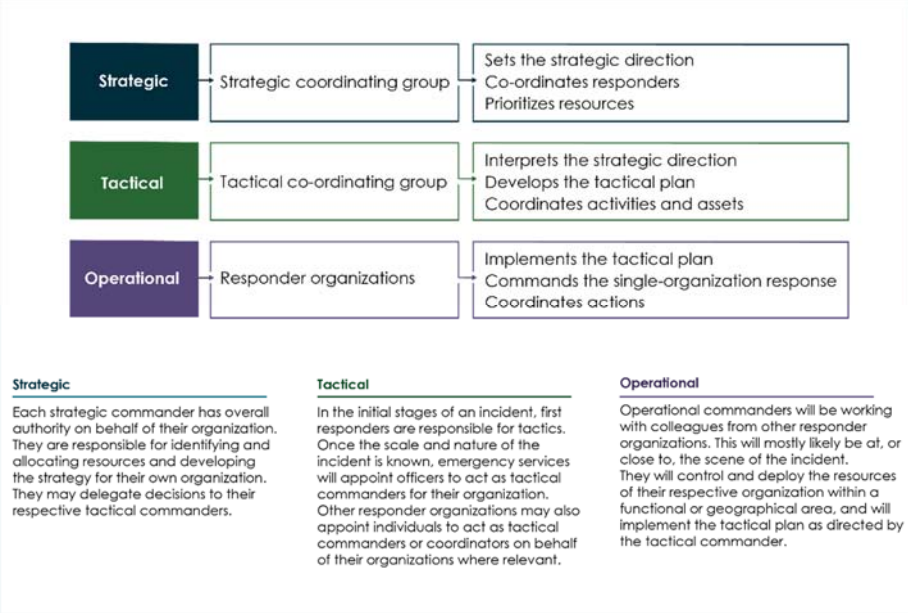

Figure 7.3: JESIP response structure

It is critical that an appropriate command structure is in place to ensure correct communication and coordination between the different command structure levels and a robust multi-agency response. Failure to do so may compromise the multi-agency response and lead to operational failings (e.g. conflicts and delays when the same means and route of transportation is being used to evacuate people at risk and to bring in equipment to undertake an appropriate response).

In addition to thinking about the command structure, the roles and responsibilities of team members – the people working together with the Flood Defence Managers – should be considered. The clear communication of instructions related to the decisions which they must implement increases the effectiveness of emergency management and response.

7.3 Communication with professional organizations

A number of professional organizations are likely to be involved in any emergency, depending on the country, its governmental structure and the scope of a flood emergency. These all need to exchange information with one another and work together, taking account of their responsibilities and capacities to carry out emergency management or to support it.

The organisations involved may include the following, each of which may have different mandates, responsibilities, capabilities and capacities:

- National or regional government.
- Local or regional authorities or municipalities.
- Health care services (ambulance and hospital services).
- Law enforcement and control (police).
- Fire and rescue (or other rapid response services).
- Local and international NGOs.
- Public and corporate organizations.

Barriers to effective communication for emergency management

In an emergency, many factors can have a negative impact on the communication between the involved professional organizations, including:

- Lack of a clear national and regional legal framework.
- Differing political agendas or conflicting priorities between organization.
- Ambitions to take the lead in an emergency solely.
- Differences in understanding of responsibilities.
- Lack of awareness, information, equipment or staff.
- Limited human and technical resources (for example, access to internet, damaged communication infrastructure).

Building long-term relationships between all involved professional organizations is essential since the sharing of information (meaning communication) is required in all phases of the Disaster Management Cycle (see Chapter 2). To work effectively together in an emergency, the organizations involved should:

- Be aware of each other's responsibilities and capacities.
- Establish professional, trustworthy relations.
- Together plan how they will communicate in the event of an emergency.

Joint training and exercises (see Chapters 3 and 15 for more information) is a good way to become familiar with each other and share information about capacities.

In an emergency, each organisation and relevant official (including the Flood Defence Managers) must receive all available relevant information about the emergency before they activate preventive measures. The professional organizations are likely to be responsible for, or know, different pieces of information, such as:

- Flood extents.
- Weather forecast.
- Number of flooded properties.
- Data on damaged territory and infrastructure.
- The degree of flooding and level of congestion on the roads.
- Resources available for humanitarian aid.
- Location of evacuation shelters.
- Number of victims and injured.

Whilst not all this information will be directly relevant to emergency management of flood defences, for effective and timely decision-making, it is helpful to provide the flood defence management team with all available data and information about a flood emergency (see discussion in Chapter 4).

Exchange of information owned or gathered by an organisation should be shared with all involved organizations in a timely manner, on a regular basis and according to the agreed format (protocol). What kinds of information should be exchanged and in what way should be agreed in advance and based on a local or relevant legal framework. Some organisations use a common platform to assist in the sharing of information.

Resilience Direct platform: supporting joint working during emergencies

In the UK, Emergency Response organizations defined under the Civil Contingencies Act 2004 use the 'ResilienceDirect' platform which is an online secure, private platform supported by the Cabinet Office which enables emergency responders to work together during the preparation, response and recovery phases of an event or emergency: https://www.resilience.gov.uk (see Figure 7.5). More information on ResilienceDirect™ can be found @RD_Gov on the 'X' social media platform.

Resilience Direct is used to share information across organisations in a secure way during an emergency and can also be used to share mapping information in the RD Mapping function. The system is also used for training and exercising and can be used outside of emergencies for day-to-day secure sharing of information between professional partners.

For example, Resilience Direct was used in October 2023 during Storm Babet and in January 2024 during Storm Henk to share information between the Environment Agency and emergency service partners so that all properties in the highest risk flood zones were known, and emergency services could use this information to warn and inform those at risk.

Figure 7.4 shows the front page of the Resilience Direct platform:

Figure 7.4: Front page of the UK Resilience Direct web platform

Netherlands National Crisis Management System (LCMS)

In the Netherlands, Emergency Response organisations use a shared system LCMS (National Crisis Management System) in which all the information about an emergency comes together and is shared within the own organisation and with the 'need to know' parties involved.

Information exchange should be supported by the following as part of the preparedness phase:

- A clear national legal framework.
- Mutual written agreements taking care when drawing up the agreements regarding information confidentiality and requirements for data protection when sharing information.
- Setting up a clear communication structure that has been created, agreed and understood in advance by all the relevant professional organizations (see Figure 7.5 for an example of a communication structure by professional organizations.) The model of communication between the professional organizations can be adapted depending on the situation, the scope of an emergency, the country, its governmental structure and available resources.

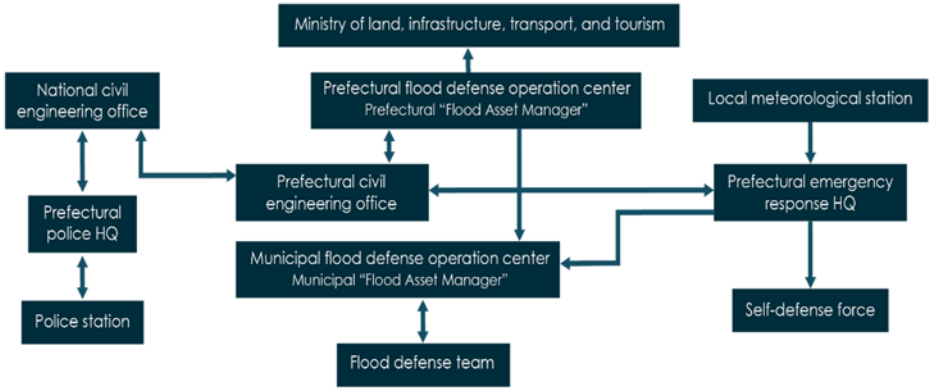

Figure 7.5: Communication structure by professional organizations in Japan

- Building personal relationships (including between contact persons or liaison officers) in each organisation in person. This will prevent blockages in communication and facilitate a better understanding of the type and scope of information that can be required when working under pressure during a flood emergency.
- Agreeing means of communication during emergencies. For example, conventional telephone lines or internet communications may be busy or non-functional due to infrastructure damage. The relevant professional organizations should therefore coordinate with communications authorities and prepare the necessary infrastructure to ensure that priority communications are available in the event of a disaster. For further details see Section 7.3.1.
- Regular joint exercises and training (see Chapter 15) involving all relevant organisations which will help personnel to gain useful knowledge and develop professional skills.

7.3.1 Communication systems for professional organisations

As discussed above, the communication methods should be agreed between the relevant professional organizations for smooth execution of the flood emergency response, ideally in advance of a major emergency. The agreements and Standard Operation Procedures (SOPs) developed in advance must define clearly the frequency, communication channel and scope of the shared information. It must be concise and understandable for all involved professional organizations. Simple templates should be developed in advance to save time and ensure timely delivery of the required information.

The communication tools should also be discussed and agreed upon among the organizations. Dedicated transceivers ensure reliable communication, but it may be difficult to distribute the necessary devices between all professional organisations or to all the communities at risk due cost. Ordinary telephones and Simple Notification Services (SNS) – through online platforms like Facebook, Twitter, Instagram, LinkedIn, and others - provide inexpensive and familiar communications. However, the analogue communication line may be cut off in an emergency. Thus, instead of relying only on the most popular or digital communication mediums like radio, internet or mobile telephone, other available means or channels to spread information must be considered (e.g., old-fashioned loudspeakers, word of mouth, community or religious leaders, volunteers, posters, booklets, etc.)

Co-location of professional partners at a nominated place (e.g. Police HQ or the HQ of your own organisation) in the event of an emergency (especially in the event of a power or communications outage) is recommended. Such co-location, ideally automatic, is a key principle for ensuring a successful multi-organisational response to an emergency (JESIP, n.d.). Co-location supports robust sharing of information and good communication.

Once these systems and protocols are in place, regular communication drills should be conducted to ensure smooth communication among all

Albert Peter Hossfeld – early example of communications during the 1953 Netherlands flooding

Figure 7.6: Albert Peter Hossfeld shortly after the flood holding his transmitter (courtesy: Ruben Oreel)

Albert Peter Hossfeld (Figure 7.6) built a radio transmitter during the Flood of 1953 in the southwest of The Netherlands to ask for help.

On February 1, 1953, the contact was made with most of the flooded areas and first aid from outside arrived. However, contact was lost with Schouwen-Duiveland (an island in the province of Zeeland) which was approximately 85% flooded. All telephone lines were down.

The next day, the first signal was received. Albert Peter Hossfeld, a radio technician had created the emergency transmitter PA0ZKR using materials from the radio workshop where he worked. By taking the initiative and creating a communication channel himself, he let the outside world know what disaster had occurred on this 'forgotten' piece of land.

Hossfeld's first plea was for aircraft to deliver life-saving supplies: rubber boats and food. He even guided relief pilots, directing them to the precise drop zones. To ensure the planes could identify his location, he ingeniously devised a makeshift signal: a red rag hoisted on a stick. The strength of his signal was astonishing, reportedly reaching as far as the Alps, a testament to his determination and technical prowess (Flood Museum in Ouwerkerk, The Netherlands).

organizations involved when an emergency does arise (see Chapter 3 for more information).

7.4 Communication with media

Media (i.e. mass communication) are important actors in every emergency, no matter small or large. They are a powerful tool to:

- Spread information required for emergency management.
- To warn and inform communities (and prevent panic).
- To keep the public aware of what has happened.
- What is being done by authorities.
- What people should do to protect themselves and their property and become more resilient.

In some countries, media outlets regardless of their ownership (public or private) are obliged by law to publish or broadcast information related to an emergency in case of urgency.

Even if there is no legal framework for cooperation, a consistent and trustworthy relationship should be established in advance by the Flood Defence Managers with the most prominent local media outlets, understand the needs of the media outlet and inform them about those of the flood defence manager. Building this relationship with media in advance helps to ensure that in an emergency your organization will be their main source of information - always available and reliable. Such a relationship will help to avoid issues such as:

- A lack of trust in, and interest to collaborate with, the authorities.
- Criticism towards emergency management professionals.
- the quick spread of misinformation, fake news or rumours, infodemic, etc.

Communications with the media should be 'with one voice'. This means that information communicated to the media by various professional organizations involved in the flood emergency response should not be contradictory. One way to achieve this in a major emergency to have a trusted spokesperson representing the multi-agency response, speaking on behalf of all partners.

Comprehensive information, such as simple explanations of flood defence activities and their achievements must be provided to all available and active media outlets on a regular basis together with attractive and high-quality visuals such as maps, infographics, also high-impact photos and videos.

When done well, good communication with the media will encourage citizens to understand the risk and the kinds of self-defence actions they should take such as evacuation and protecting property. (The importance of public awareness and preparedness is discussed in Chapter 3.) This will help to reduce the workload of flood emergency response and allow the professional team to focus on their technical activities to implement flood defence interventions.

Misinformation and disinformation

Misinformation refers to false information provided without an intention to cause harm.

Disinformation refers to false information that is intended to manipulate, cause damage, or guide people, organisations and countries in the wrong direction.

For further details see Canadian Centre for Cyber Security (2022).

BBC Radio Lincolnshire embedment in County Emergency Centre

The Lincolnshire Local Resilience Forum on the East Coast of England (see: https://www.lincolnshireresilienceforum.org/), which consists of partners operating under the UK Civil contingencies Act 2004, embeds BBC Radio Lincolnshire colleagues in the County Emergency Centre during an emergency. This is done with the agreement that during an emergency they support the partners by sharing crucial warning and informing messages with the public and work with the emergency services to reduce risk to life. This

relationship is built on trust and has provided invaluable support in sharing messages with the public during actual emergencies. After the emergency, they can take a more traditional media role and hold the partners to account for their actions. This relationship helps the authorities rapidly deliver messages to the population about any urgent action they should take to minimize risk to life.

Importance of public awareness and prior education for emergency preparedness – example from Greece

Severe flooding occurred in various regions of Greece, Bulgaria, and Türkiye in early September 2023 due to the intense rainfall brought by Storm Daniel. The Thessaly Region in central Greece experienced particularly devastating floods as a result. Numerous calls for assistance were received by the Greek Fire Service during this emergency (Davies, 2023).

People in many places were asked to evacuate, including the residents of the city of Larisa. The evacuation order was sent with automated (SMS) messages to the residents of Larisa but instead of guidance, this message created even more confusion. The original message said: "If you are within the flood zone of the Pineios River on the boundaries of the Municipality of Larissa, evacuate due to the risk of river overflow. Follow the instructions of the Authorities." The same message was posted on the official account of the Ministry of Climate Crisis and Civil Protection of Greece which shares information from the Greek 112 emergency service (see Figure 7.7).

From the posts and comments on social media, it becomes obvious that the warning message raises more questions rather than bringing clarity to the people being in danger. Receivers were asking what exactly is the extent of the flood zone of the Pineios River? Where should they go and how? Is transportation available? What about disabled and older people? Someone stated that after living in this area for 20 years this was the first time they learnt about the 'flood zone of Pineios' (https://twitter.com/112Greece).

This example highlights the importance of public awareness and prior education for emergency preparedness. If the population of the flood-prone regions had been informed about evacuation plans and which authorities were responsible for flood defence management, they would not have been confused by the warning messages and would know have known what actions they needed to take to be safe.

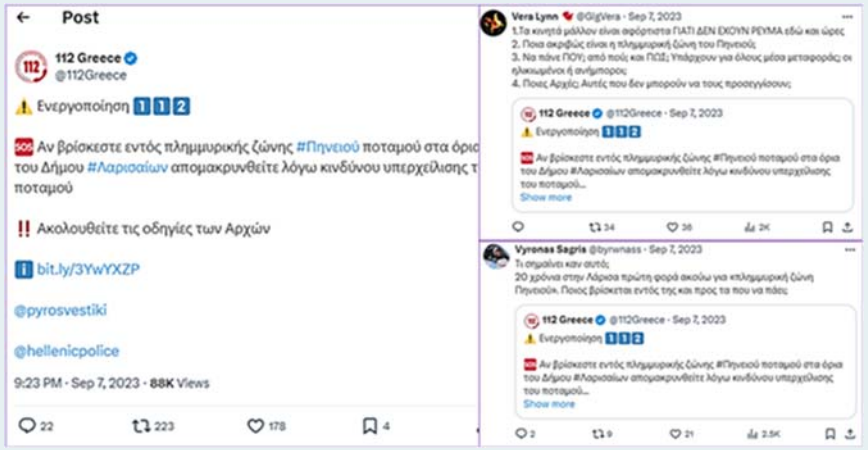

Figure 7.7: Examples of 112 Greece warning message and comments of users on Twitter (Ministry of Climate Crisis and Civil Protection of Greece, Official Twitter account '112 Greece', https://twitter.com/112Greece, last accessed on March 6th 2024).

7.4.1 Infodemic and media monitoring

In any emergency, there is a huge demand for information. People want to know what has happened and what is the main threat to their lives, health and property. Thus, they tend to seek information from many sources, without necessarily considering whether the source of information should be trusted. In such a situation an infodemic should be prevented as soon as possible, where an infodemic is 'a constant chaotic flow of controversial information, usually from unchecked sources' (Bari & Alaverdov, 2021). To do so, the organization responsible for the flood emergency defence must take the lead on communication for emergency management immediately and try to fill in all news 'gaps' with comprehensive and trustworthy information.

Flood Defence Managers are recommended to work with their professional partners to create a system for the regular monitoring of

highly rated popular media outlets (preferably on 24/7 basis) with two functions:

- To evaluate the effectiveness of distributed information.
- To screen public opinion about the current emergency and measures taken by the authorities.

Well-structured regular media monitoring will also help to spot quickly warning signs of dissatisfaction or criticism by the public, rumours and fake information. By swift identification of false information or criticism, the Flood Defence Managers will be able to react rapidly and clarify those by delivering fresh data on the current situation, relevant statistics and visuals to support their main message.

'Warning and informing' media cells in England

In England, the Local Resilience Forums (LRF) set up multi-agency 'Warning and Informing cells' which coordinate communications with the media and the public. The LRF is the multi-agency group that comes together to respond to major emergencies and the cell coordinates a single message for all partners.

7.4.2 Spokesperson for media relations

A clear vision and strategy for media relations should be established in advance of an emergency occurring. A key element of successful media relations is having a knowledgeable and well-trained spokesperson. This should be a professional from the Flood Defence Management Team which consists of representatives of the involved professional parties (police, fire and rescue services, municipality, hospitals, etc.). The assigned spokesperson should have advanced communication skills and enough experience in emergency management to be able to communicate with media effectively when needed. The communication best practices advice for a spokesperson to prepare for media interviews is as follows:

- Present information clearly without scientific jargon.
- Do not use the phrase 'No comment' otherwise people may think that you hide something or do not aware of the situation.
- If you don't know the answer – be honest and upfront about this.
- Do not make assumptions and rely only on the checked facts.
- Never repeat false information appearing in the questions.
- Try to avoid distracting or nervous gestures (e.g., fidgeting, pacing, touching your face, etc.).
- Have strong eye contact.
- Be mindful of where you are undertaking the interview – ensure there are no distractions or an unhelpful background.
- Limit the disfluencies like 'uhm' or 'uh'.

Professional media training should be provided to the most likely media spokespersons in the flood defence management team. This training is beneficial for all parties because it will help them to gain a better understanding of the implications of the flood emergency.

Representatives from the media should also be invited to the training or regularly included in various simulations and exercises. Whilst these media representatives may be communications professionals, they might not be familiar with the technical aspects of flood defence and need training to gain a better understanding of defences and the potential emergencies associated with them, since those can have different contexts, duration, and cause different types of damage.

FEMA Joint Information Centre

The Joint Information Centre (JIC) is a system developed by the Federal Emergency Management Administration (FEMA) of the U.S. to coordinate the communication for emergency management between Flood Defence Response organizations and media. JIC is an effective concept can operate at different levels – community, regional, or governmental including public and corporate organizations. JIC can also operate both in a physical location and virtually - by phone or online (FEMA, 2024).

FEMA recommends establishing a JIC as a part of an Incident Command

System to have immediate access to all kinds of information. In general, JIC accomplishes the following tasks:

- Executing communication plans and strategies.
- Development and delivery of coordinated interagency ('one voice') messages.
- Advising the Incident Commander (in this case, the Flood Emergency Manager) concerning public affairs and communication for emergency management issues.
- Identifying and addressing rumours and misinformation that can distract an emergency management.

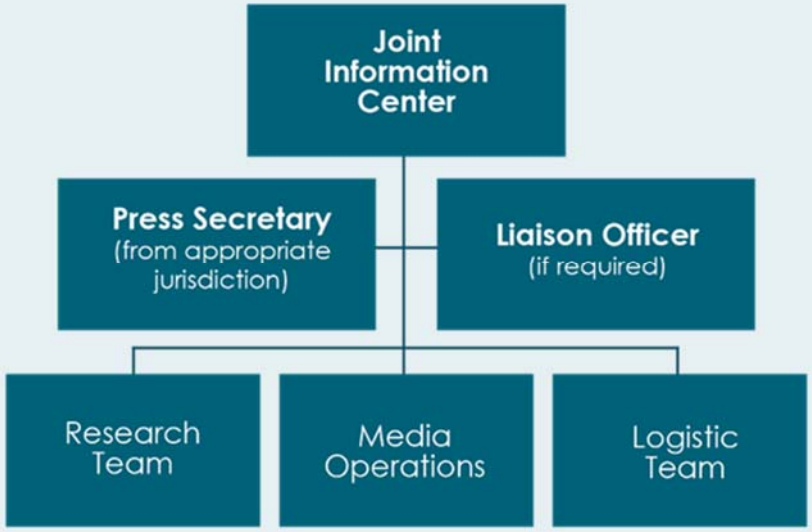

Figure 7.8: Structure of a Joint Information Centre (JIC)

In the JIC structure shown in Figure 7.8:

- Press Secretary takes the role of a spokesperson..
- Liaison Officer ensures communication between the professional parties involved
- Research Team collects the flood emergency-related data and prepares messages for media and the public.
- Media Operations unit disseminates messages and high-impact visuals on different media platforms and other available communication channels.
- Logistic Team is responsible for the steady operation of the equipment and other logistical issues.

7.5 Communication with the public

Communication with the public is closely linked to communication with the media, as explained in previous section. It is critical when communicating to recognise that there are a variety of people with different abilities to receive, deliver, and understand information. Particular attention must be paid to people who are less well-served, especially those who have difficulty accessing media coverage, to ensure that no one is neglected or not provided with emergency advice. A range of modern and traditional tools and methods should be used, along with indigenous knowledge, to ensure communications reach all parts of the communities that are at risk.

Commonly used tools and methods for communicating with vulnerable people are:

Simple Notification Services (SNS) and other Internet media. In recent years, smartphones and the Internet have become widely available, even to vulnerable communities, making information provision through SNS very effective. In addition, if a family or even a part of the community has access to such Internet status, the information can be easily shared with the entire community. Furthermore, the recent evolution of free automatic translation services has reduced language barriers to almost zero for the Internet media.

Multi-language information dissemination via public speakers. Public speaker systems are conventional but very effective especially in areas where Internet access is not available. Loudspeakers that can reach large numbers of residents with a single announcement are most useful in times of disaster, when speed of information delivery is critical. On the other hand, since the information must be delivered by voice alone, it is necessary to keep the information simple and understandable, and the announcements should be made in multiple languages as needed.

Face-to-face communication by community leaders and residents. In the most vulnerable areas, where there is no internet or electricity, face-to-face communication is the only option. In this case, the credibility of the community leader is paramount. Part of good preparedness is therefore working out how to get information to community leaders quickly.

Automated warning and informing messages. These can reach a wide group of people instantaneously.

UK Government Emergency Alerts System

This is a service that warns members of the public if there is a danger to life nearby. In an emergency, your mobile phone or tablet will receive an alert with advice about how to stay safe and the government does not need to know your phone number or location to send you an alert. See: https://www.gov.uk/alerts

Environment Agency Flood Warning Service for England

This service provides Flood Alerts and Flood Warnings to the public to advise them on the actions to take during flood emergencies. It is the way in which the flood risk management professionals in the Environment Agency communicate risk to life to the public. It varies from a Flood Alert ('Be prepared'), to a Flood Warning ('Take action as property flooding is expected') to a Severe Flood Warning ('Imminent risk to life – take action to survive'). The service (see Figure 7.9) is free and members of the public can sign up to receive these alerts whether they live in the at risk areas or not. At the time of writing this handbook, the following webpages provide more information on

(a) How to sign up for the service https://www.gov.uk/sign-up-for-flood-warnings ;

(b) Details of the live warnings https://check-for-flooding.service.gov.uk/alerts-and-warnings.

Figure 7.9: Flood warning service advertisement

7.6 Communication between international organizations

Different countries and their organisations have developed their own systems and tools for emergency management of flood defences. They are also exposed to different risks at different times and frequencies and in differing geographies. Despite these differences and as discussed further in Chapter 15, Flood Defence Managers can learn from each other to better support emergency response and minimise risk to life. To

help to improve the way the professionals respond and support communities. it is worthwhile sharing:

- Principles of their approaches.
- Skills, knowledge and experience gained through past emergencies, such as how to improve Health Safety and Wellbeing aspects of emergency response (see Chapter 13).
- Equipment and methodologies adopted.

Community-based Flood Information System (CFIS)

One of the lessons learnt from the many floods in Bangladesh was that the local community needs flood information in their local context to prepare adequately at household and community levels. The existing flood information from the Flood Forecasting and Warning Centre (FFWC) has been criticized by the local people for being not easily understandable and out of local context.

Considering this, the FFWC, in collaboration with some external parties, has initiated a pilot project in a few flood-prone areas of Bangladesh. The main idea was to build an interactive process of flood information collection and dissemination to various stakeholders. The CFIS was learning from the community and development of an effective model for local level flood warning and dissemination of information related to monsoon floods in floodplains. The project generated useful flood information during the flood of 2004, proved to be helpful to the local community (Mallick et al., 2009).

International exchanges enable flood defence professionals to share their ways of working across countries and to highlight what approaches work well or could be improved. Whilst observing how organisations respond during a live emergency is hugely beneficial, such sharing is best done during the preparedness phase (e.g. during an exercise) ideally outside the build-up to an emergency. The sharing of best practices strengthens the preparedness and response of international partners in their own countries. A few approaches are directly transferable, such as the use of the 'Emergency Alerts' cell broadcasting technology to warn and inform the public (see section 7.5), which is now used in over 20 countries. When establishing information and knowledge-sharing exchanges, it is worth developing a Memorandum of Understanding to ensure all involved parties understand their role and remit.

England/Netherlands Incident Management Exchange

The Environment Agency, Dutch Regional Water Authorities, Rijkswaterstaat and other Drainage Authority colleagues have been undertaking an Incident Management Exchange since 2017. This has been a useful way to share information and best practice in peacetime as well as visit each other during emergencies (see Figure 7.10). For example, Dutch colleagues came to England in 2019 to observe the local response to the major flood emergencies in Lincolnshire, England, where there had been a failure in a flood embankment and the evacuation of properties because of flooding.

Figure 7.10: Dutch and English colleagues on an incident management exchange in Lincolnshire, November 2023, following damage caused by Storm Babet (October 2023) (Courtesy: Ben Thornely)

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CHAPTER 8

Assessing and inspecting

Key messages:

- **Proactively identify vulnerable areas**
- **Inspect to identify rapid interventions**
- **Keep safe when inspecting during floods**

Figure 8.1: Structure of the handbook

Other places to find information on the topics of this chapter

Chapter 2: Inspections within the broader context of emergency planning and role division

Chapter 3: Early warning systems as trigger for inspections, guidance for inspection planning and role of inspections for flood defence performance assessment

Chapter 4: Basic principles of early warnings. Response actions following inspections

Chapter 6: Flood defence types to be accounted for in the preparation of inspections

Chapter 7: Public communication of inspection findings

Chapter 9: Failure mechanisms linked to anomalies detected during inspections. Visual clues for the initiation of every failure mechanism that inspectors can observe in the field.

Chapter 10 and 11: Selection of emergency measures based on inspection results

Chapter 12: Connecting the field team (assessing/inspecting) to logistical considerations of measures to be implemented

Chapter 13: Health, safety and wellbeing considerations during inspections

Chapter 15: Lessons learned from inspections

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The Reader is kindly requested to take note of the Disclaimer on page ii of this handbook.

Chapter title page photograph:

Inspection of a flood defence before the rainy season (courtesy: MLIT)

Key messages:

- **Proactively identify vulnerable areas.** A proactive identification of vulnerable areas along flood defences allows inspection teams to strategically prioritize their efforts during on-site assessments.
- **Inspect to identify rapid interventions**. Conducting on-the-ground inspections of flood defences during emergencies enhances the efficacy of rapid interventions, thereby mitigating the risk of structural failures and flooding.
- **Keep safe when inspecting during floods**. On-the-ground inspections of flood defences in emergency situations typically occur under adverse conditions, necessitating strict adherence to safety protocols.

In the event of high-water levels or other water emergencies, early warnings and flood defence inspections are important parts of the emergency response as follows:

- Inspection of flood defences helps to identify potential problems and weaknesses in the flood defence system that potentially could lead to a catastrophic failure. If the flood defence is being monitored prior and during an emergency, the information is available to decide which emergency response measures should be adopted to strengthen the flood defence, thus preventing failures.
- Early warning systems can be used to alert flood defence managers to the expected levels of high water so they can prepare emergency response measures. It is the trigger point to start (preparing) the inspection (see also Chapter 3).
- Early warning systems can also be used to inform the public about expected high water levels or intense wave activity. Such warnings help them to be prepared and take measures if they live in endangered areas (see Chapter 7 on public communication and media approach regarding flood warnings).

This chapter provides guidance on

- Section 8.1 – early warning systems that might trigger an inspection of a flood defence during the emergency.
- Section 8.2 – condition assessment and setting of priorities.
- Section 8.3 – preparing for inspections and incorporating inspections in organisational processes.
- Section 8.4 – inspection and monitoring during emergencies.

Examples of the mentioned basic principles of early warning and inspections and tips for improving inspection processes are placed in text boxes. Experiences and best practices in assessments and inspections should be shared within and between organizations and countries (see Chapter 15).

8.1 Early warning

Early warning plays an essential role in mitigating the impacts of potential flooding (loss of life and socio-economic damage) by providing timely and accurate information to communities and authorities, so that they can prepare emergency response measures. It is the trigger to begin preparation for inspection before and during periods when there is maximum load on flood defences (see Section 4.2).

Early warning systems involve the collection and analysis of information from various sources which are discussed in the following.

This information helps in predicting when and where potential flooding might occur. When there is a potential threat of flooding, early warning systems can be used to alert and inform relevant authorities and potentially affected communities. The responsible authority should take care that all relevant staff (at the office and in the field) are informed about the actual and predicted conditions.

Community-Based Flood Early-Warning System, India

In 2013, five community-based flood early warning systems were installed on the Singora and Jiadhal rivers. The system issues flood warning signals to 20 flood-vulnerable communities on the Singora River downstream and 25 flood-vulnerable communities on the Jiadhal River (see Figure 8.2).

During the flood season of 2013, the Jiadhal River flood early-warning system saved assets and lives (including cattle and pigs worth approx. USD 3,300 by successfully informing community members of pending floods and helping them to prepare and respond to the potential flood threat. The system also enhanced cooperation between upstream and downstream communities in sharing flood information.

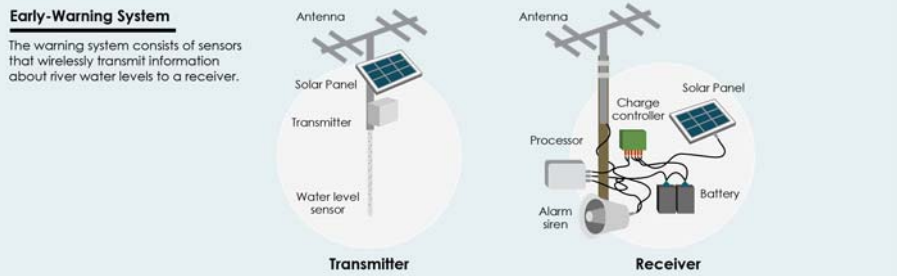

Figure 8.2: Early warning system, consisting of a sensor that wirelessly transmits information about river water levels to a receiver (more info at Momentum4Change.org) Ref: Community-Based Flood Early-Warning System \| India \| UNFCCC

Early warning systems in the United States

Several early warning flood systems are operational across the United States, helping to mitigate the impacts of flooding events:

National Weather Service (NWS) Advanced Hydrologic Prediction Service (AHPS)
The NWS AHPS provides river and flood forecasts for thousands of locations across the United States (see Figure 8.3). It uses data from various sources, including stream gauges, rainfall measurements, and weather forecasts, to predict river levels and issue flood warnings. These forecasts and warnings are crucial for emergency management agencies and communities to prepare for and respond to flooding events along the Mississippi River and its tributaries.

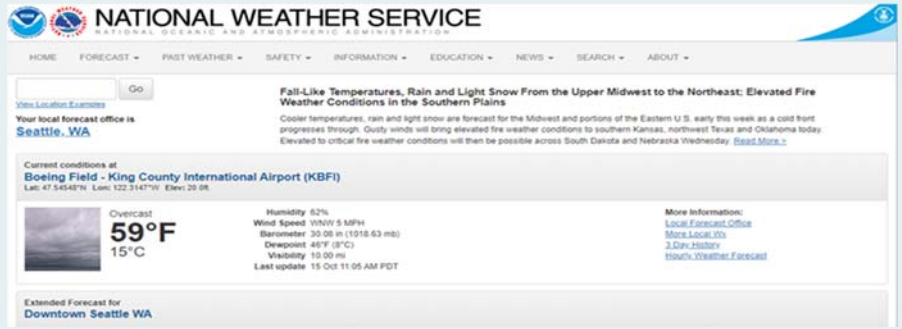

Figure 8.3: Screen dump of weather prediction of the NWS, US

- Flood Warning Systems in Major River Basins.
- Many major river basins in the United States have their own flood warning systems operated by federal, state, or local agencies. For example:
  - The Lower Mississippi River Forecast Center issues forecasts and warnings for flooding along the Mississippi River and its tributaries.
  - The California Nevada River Forecast Center provides forecasts for flooding events in California and Nevada.
  - The Northeast River Forecast Center covers river basins in the Northeastern United States.
- Automated Flood Warning Systems.
- Various cities and municipalities across the country have implemented automated flood warning systems that use sensors and gauges to monitor water levels in rivers, streams, and urban drainage systems. These systems can trigger alarms and notifications when water levels rise to potentially dangerous levels, allowing for timely evacuation and emergency response.
- Integrated Flood Early Warning Systems.
- Some regions have implemented integrated flood early warning systems that combine data from multiple sources, including weather forecasts, radar imagery, river gauges, and hydrological models. These systems provide comprehensive and real-time information about flood risk, allowing for proactive decision-making and response planning.

8.1.1 Meteorological forecasting

Meteorological forecasting involves a continuous forecasting of weather conditions, including rainfall, temperature, wind speed and direction. This information can be obtained from national weather services or from local meteorologists. National weather services can also often provide forecasts of river/sea water levels and wave conditions (see also 8.2.2)

Meteorological and wave/water level predictions are needed to prepare for high-water events, including flash floods. The information is crucial to be able to estimate the level of risk to the flood defence and to allow flood defence inspectors and response teams to adequately prepare. In the days prior to a high-water event, responsible authorities/emergency response teams should closely monitor these forecasts to stay informed about any impending storms or heavy rainfall.

8.1.2 Hydrological and hydraulic conditions

It is essential to observe and predict hydrological and hydraulic conditions and note any changes with time. Hydrological and hydraulic measurements and forecasts include water level and wave conditions, soil moisture, snowmelt and groundwater levels. This monitoring can be conducted using a variety of methods, from using satellite imagery, to measuring via conventional gauges (see Figure 8.4).

In the field, a close monitoring of the hydrological conditions in the days leading up to a high-water event is essential.

Figure 8.4: Traditional water level gauge.

High water levels in the river Rhine in Germany triggered extra monitoring downstream

In 2019, water levels of the river Rhine in Germany were high. Precise water level information from Germany enabled prediction of the corresponding downstream water levels for the reaches controlled by the Dutch Regional Water Authority De Stichtse Rijnlanden. Satellite imagery was used to identify locations where the flood would reach or exceed predefined flood levels. These locations were inspected in advance of high-water levels reaching the area, not only to monitor the condition of the flood defence, but also to locate areas where beavers might dig burrows.

8.1.3 Data from other sources.

Other warning signals that may trigger inspection or control of the defences and extra vigilance around embankments may come from sources such as:

- War and terror threat. The national government may issue warnings for e.g. terrorist attacks. This requires advice on which objects are potential targets and how to deal with inspection during the alert phase.
- Local threat. Police or civil authorities can issue an alert phase regarding unrest by (local) people who are affected by emergency measures.
- Cyber-attack. Cybercriminals can target flood defence organisations daily to blackmail the flood defence management organisation.
- Earthquake (post-earthquake inspections). In earthquake areas it is required that potential impacts of earthquakes on embankments and related flood defence infrastructure are known.
- Forest fires in areas close to flood embankments with trees. The impact of a heavy fire on the embankment, especially its grass cover, should be known.

8.2 Condition assessment and setting of priorities

8.2.1 Flood defence condition

To ensure a good inspection, it is important to have a thorough understanding of the flood defence system, its actual condition and its functioning, including related infrastructure (weirs, pumping stations). Inspection is an essential means to achieve a sound assessment of the situation at the flood defence (risk assessment).

The following asset information related to the strength and resistance of the defence can be obtained through a combination of inspections and historic records:

- Condition of the flood defence system and its infrastructure, including information from any maintenance and inspection records.
- Identified vulnerabilities or potential risks from a flood (debris, floating material, and tree trunks).

- Groundwater and phreatic water levels.

A distinction should be made between regular/planned inspections and incidental inspections during high-water situations. Their aims are different:

- Routine inspections. Over time, the strength of the flood defence system may degrade, due to different processes, like subsidence (of the flood defence and/or of the hinterland) and crack formation. Regular monitoring of geometric and/or geotechnical changes over time through inspections allows the identification of any reduction in the strength of the flood defence, especially if the change means that the flood defence no longer meets the design requirements including withstanding the design loads. Regular inspections should be planned and implemented on a regular basis (for instance, twice a year – before and after the storm/high-water season). Regular inspections include the monitoring of visible damage that indicates vulnerabilities or potential risks. The results of inspections are used to identify measures so that the embankment can fulfil its functions again.
- Inspections during high-water conditions. These inspections can be initiated by the information from early warning systems, or from sensors, positioned in the flood defence, that show critical or even alarm levels. Advance assessments of vulnerable locations of embankments under high-water conditions should be used to identify low or weak spots of a flood defence under construction or repair and areas where problems of erosion or loss of stability may occur.

Depending on the importance of the flood defence and/or its sensitive zones identified to date, the installation of a flood defence sensor system should be considered. The aim of such a system is to collect detailed information about local conditions of flood defences and about the development of internal deterioration processes on a continuous basis. Data from a sensor system could also be used to monitor the condition of a flood defence during a flood and/or to assess its condition after a flood or for routine condition checks. The data could also be used for designing a (new or rehabilitated) defence and for day-to-day management and maintenance. A broader description of embankment monitoring strategies in combination with other methods of their examination and observation is described, for example, by Radzicki et al. (2021).

Inspection of flood defences along the Romanian coast

The management of emergency situations generated by dangerous hydrometeorological phenomena in coastal areas of Romania is governed by the Romanian Joint Order of MWF / MAI – 459 / 78 / 2019 – REGULATION. Phenomena included are any that might result in floods, drought as well as incidents / accidents at hydrotechnical constructions, pollution of water courses and marine pollution. The inspection of marine flood defences is carried out by the RBA -Water Management Systems (WMS). After each high-water situation, the WMS carries out an additional inspection of the flood defences. The findings are recorded in a technical report with follow-up recommendations.

Regular inspections are scheduled in autumn when Romanian authorities and organisations who are responsible for emergency management organise joint teams to check vulnerable / critical areas of flood defences. The objectives of the regular inspections are to prevent failures of the defences and the verification of emergency supplies and equipment, as well as dissemination of Flood Hazard and Risk Maps to the public. These assessments are the basis for prioritizing funding and proposed works (see Figure 8.5), resulting in a plan of interventions, including deadlines for completion and people/institutions responsible for implementation.

Inspection of hydrotechnical constructions which are permanently under water are only carried out when the reservoirs are drained for scheduled repair work.

Figure 8.5: Repair of coastal flood defences in Romania (courtesy: Cristian Barbu)

Value of monitoring using sensors proved in smart flood defence experiments in the Netherlands

The results of large-scale experiments (such as the IJkdijk experiments in the Netherlands, see Figure 8.6) show that the combination of different models and sources of data from sensors establish a better, more reliable understanding of flood defences. As a result, a qualitative improvement is possible in all activities in the life cycle, leading to improved priority-setting for the work required, and to improvements in flood protection.

Figure 8.6: Testing and monitoring dike strength in the IJkdijk, The Netherlands

Use of thermal sensing system for leak detection in flood embankments in Poland

A local thermal sensing system for leak detection was installed as a pilot in flood embankments on the Vistula River. The objective was to allow monitoring during high water levels and to support post-flood flood embankment assessment.

Various methods, like visual inspections and geophysical surveys, can be used to detect zones on flood embankments where deterioration processes are ongoing. When the number of such zones is substantial, reliable information on the progress of deterioration processes and seepage is crucial to take decisions on emergency response measures during high water levels or after the floods have receded.

To obtain more precise information about the condition of flood defence structures, the Multi Points Thermal Monitoring System (MPointS) has been developed for the detection of leaks and erosive processes. Its primary components are thermoactivated (heated) sensors, which enable unequivocal leak detection, assessment of leak development even by non-experts or by automatic systems, and in-situ measurement of seepage velocity. The system installation is both swift and straightforward, by inserting sensors from the surface to a predefined depth, side by side. Importantly, this permits the creation of a quasi-continuous monitoring line along the flood embankment.

The MPointS sensors were installed in 2017 in the body and substrate of several sections of the flood embankment in Wawrzeńczyce village, where leaks had been observed during previous high-water levels (Radzicki et al., 2021). During subsequent high-water levels, the sensors enabled the monitoring of leak development. This influenced the subsequent decision to undertake repairs to the flood embankment at this location.

This system is now to be installed on additional flood embankments where intensive seepage zones or leaks have been identified (see Figures 8.7 and 8.8). It is expected that information from the leakage monitoring system will be utilized for more precise assessment of flood embankment conditions after the flooding. Modest high-water levels will enable the collection of data concerning the flood embankment's state, facilitating the execution of precise and optimized repairs before the occurrence of critical flooding. In the future, if flood embankment monitoring centres are developed in Poland, the MPointS systems will also provide flood embankment monitoring during flooding, with the aim of identifying areas requiring immediate reinforcement.

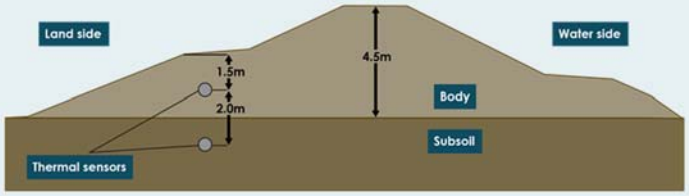

Figure 8.7: Location of MPointS sensors in the Wawrzeńczyce flood embankment's cross-section (Radzicki et al., 2021)

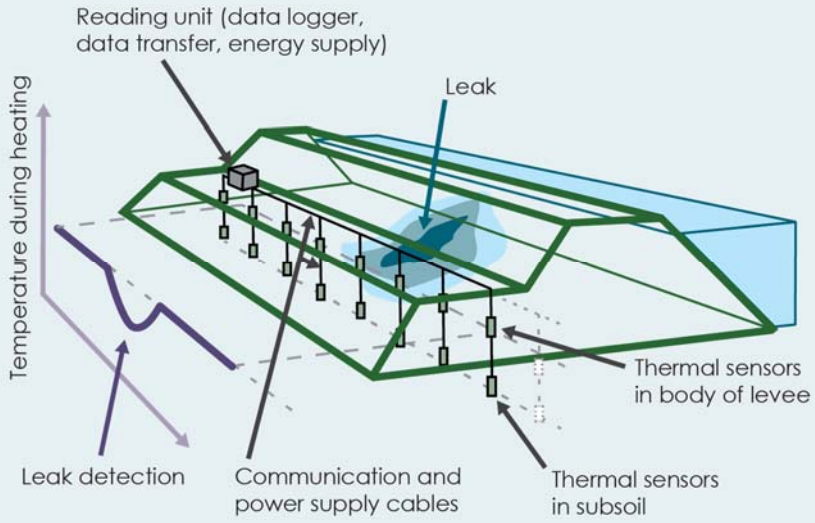

Figure 8.8: MpointS system for quasi-linear monitoring of leaks (Radzicki et al., 2021)

Inspections of flood embankments should also be carried out during prolonged dry spells (Waternet, n.d.). The reasons for such inspections vary according to the material of the flood embankment.

- Peat. Embankments consisting of peat become lighter in weight when the peat dries. The reduced weight can reduce the stability of the embankment and allow the pressure of the water to cause the embankment to shift and fail (see Figure 8.9).
- Clay. When clay embankments dry out cracking of the protective cover layer may occur, leading to gullies where rain may erode the cover and encouraging internal erosion.
- Sand. When sand embankments dry out the vegetative cover may get into a very poor state. During prolonged drought periods, grazing may need to be stopped to prevent further deterioration of the vegetation.

Figure 8.9: Failure of a peat embankment in Wilnis, The Netherlands (2003)

8.2.2 Priority setting

Inspection information can be used to prioritise special inspections during high-water stages and any response strategies to protect key flood defences (see Chapters 10 and 11). This priority setting can also be used in case of limited number of inspectors and/or limited budget.

When planning for inspections, a risk assessment should be carried out to prioritise flood defences:

- That are the more weak or vulnerable (see Section 4.2.2) based on regular inspections and/or inspections during high-water events.
- Where failure of the defence has higher consequences. (Assessment reports should identify those defence lengths that meet the standards and those that are inadequate (see Section 4.2.3).
- Where inspections are required to check that action instructions have been executed and are leading to reliable functioning.

8.3 Preparing for inspections

After the risk assessment and decision about which flood defences need to be inspected, preparations should be made for the actual inspections. This should start a few days prior to the inspections and should be based on instructions that are laid down in handbooks, maps and/or inspection apps. The instructions should be available to the inspectors and the flood defence experts (in the field or in the office) to whom they report

Inspection of flood defences in Louisiana, US

The Southeast Louisiana Flood Protection Authority-East oversees operation and maintenance of the portion of the new, $14.5 billion, storm protection system on the east bank of the river, constructed following Hurricane Katrina (2005). A team of flood defence inspectors for the authority now conducts regular (four times a year) inspections of the flood defences (see Figure 8.10). All inspectors are required by the newly created state Coastal Protection and Restoration Authority to pass a one-day training program.

The defences to be checked in Orleans Parish include 39 Miles of floodwalls, 117 miles of flood embankments, 204 floodgates and 102 flood valves. Proforma checklists are used to record findings, which are summarized and sent to the US Army Corps of Engineers and the State. Special attention is paid to settling, sloughing or collapsing of soil, growth of trees and other unwanted vegetation, illegal buildings, and the health of the grass. In addition, a team of eight employees checks the functioning of hundreds of gates and valves daily.

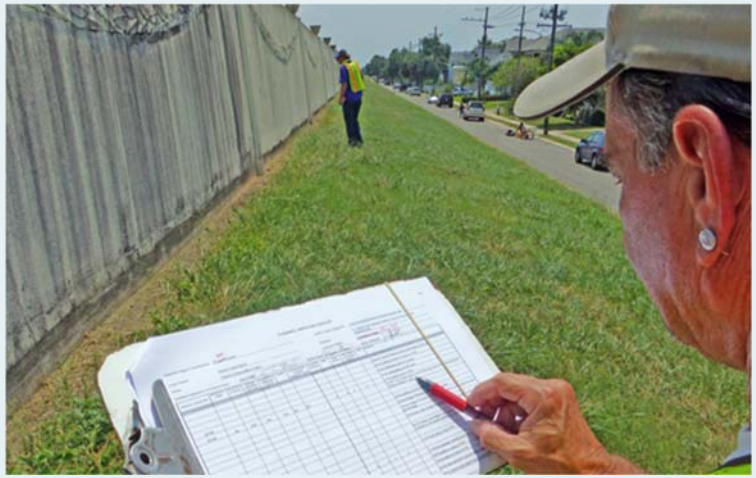

Figure 8.10: Inspector consults a checklist while walking the Orleans Outfall Canal during a quarterly inspection of the metro area's new hurricane protection system.(Credits: Bob Marshall/The Lens)

8.3.1 Characteristics of the flood defence

Prior to inspection, the inspector should have a thorough understanding of the flood defence system and its components. This helps them to understand how the flood defences should function, including their many components, so that inspection results in a proper identification of potential weak locations. This knowledge should also include design details of the flood defence (e.g. thickness of clay cover), materials used, the use of the flood defence (e.g. by livestock, farmers), the dimensions, type of structure, ditches near the toe of the flood defence, etc.

Checking cattle pathways and drinking spots

In several places there are issues about cattle pathways and cattle drinking places (see Figure 8.11). These locations may cause problems with the flood defence stability. Inspectors should be asked to specifically check these locations.

Figure 8.11: Example of deterioration of an inner slope due to cattle

8.3.2 Historic analysis

Proactive maintenance, regular inspections, and flood defence improvements by the responsible organisations are needed to keep a flood defence system functioning. Next to knowing the details of the flood defence, additional vulnerabilities and limitations can be identified by analysing historic flood events and maintenance. This may give insight into past repeated breaches or weaknesses, that form an indication for specific interventions. These past events can be visualised for inspectors on maps or inspection apps.

Wielen: remains of past breaches

Along the river Rhine in the Netherlands many, historic breaches (18th century and older) have resulted in so called 'Wielen' inland of the repaired flood defence (see Figure 8.12). These inner ponds illustrate the locations of the breach, developed due to erosive forces in the breach. They are placed on the maps the inspector uses in the field, giving them a better understanding of where to look. Depending on when the breach occurred, the repair might not be to current standards, creating a weak spot.

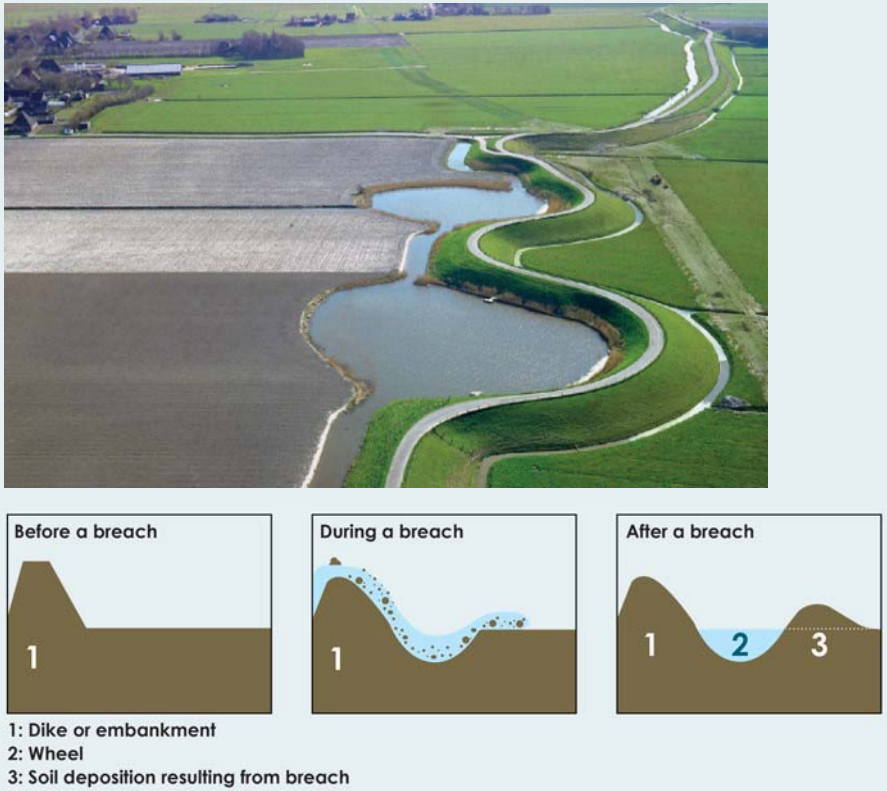

Figure 8.12: Wielen located along inland water courses and a schematic explanation (de Vree, n.d.)

8.3.3 Characteristics of the flood prone area

To ensure the safety of inspectors, knowledge of the flood prone area is needed. Understanding the water flow and potential impacts of a breach, overtopping event, or failure allows inspectors to know the way to leave an area safely and quickly. For this, a floodplain map of the area, including elevated roads and evacuation routes, is required and may be included within the inspection app.

8.3.4 Awareness of the hazards/dangers of inspections

Inspecting a flood defence system during high-water and storm conditions can be a dangerous activity. While executing their work, inspectors should be aware of their own and others health, safety and wellbeing. Health, safety and wellbeing should also be facilitated by the responsible organisation for its own staff as well as for volunteers that join such inspection (see Chapter 13).

Traffic conditions, poor visibility, and local weather conditions (rain, wind, cold temperatures) can negatively influence a safe inspection. Working on flood embankments, especially under high-water and/or stormy conditions, poses threats to personal safety such as.

- The state of the flood defence, such as:
  - Animal burrows covered by high grass causing inspectors to stumble.
  - Slippery flat, and especially sloping, surfaces made wet due to rain.
- High wind velocities hampering safe walking.

Given such hazards, appropriate precautions must be taken prior to the inspection. Chapter 13.3. explains how to make a hazard assessment to identify which personal protection equipment is needed and how the inspection should be prepared (instructions and toolbox).

By advance training, awareness raising and ideally walking together in a group with (trained) inspectors, the risk of personal injury can be reduced. Even if group working is not possible, lone working should be avoided and mobile phone or tablet based systems which include a GPS tracker can be used so that colleagues (e.g. in the office) can check the location of others during an emergency. Good personal care (food, resting time, clothing and communication equipment) is also strongly advised.

8.3.5 Gear, tools and equipment

In general, the following gear, tools and equipment are advised (see also Figure 8.13):

Per team

When inspections are carried out by teams, it is advised to provide each team with a backpack containing:

- Map with the route marked out and the parking areas indicated.
- Key guidance information.
- List of important telephone numbers, including of the flood defence organisation.
- Instructions for use of any inspection app.
- Pencils.
- Damage report forms.
- Equipment such as measuring tape, chalk/road paint, a flag to mark anomalies.
- Snacks and drinks.
- First aid kit.
- Rope or lifeline for use when working near water.
- Keys for access gates on and near the flood defence.

Per inspector:

- A charged smartphone or tablet with an inspection app, allowing prolonged work without recharging.
- A power bank. When using GPS and sending info, the battery can drain quickly especially during cold conditions and/or poor reception conditions.
- Probe, to identify soft or hard soil in the flood embankment.
- Personal Protection Equipment suitable for the weather and field conditions. For example, a (yellow) safety vest is required for visibility of colleague inspectors and for road traffic.
- Appropriate clothing and accessories such as a hat, sunglasses, sunscreen, a coat and/or fleece jacket for all types of weather, and spare socks.
- Rubber boots (or hiking boots with gaiters as appropriate) for wet areas and ditches.
- A head lamp, flashlight and batteries, an arm lamp to be visible and to see the flood defence.
- A life jacket, if necessary, when walking close to water (e.g. cold, with strong currents).

Tips

1. Use a *probe made of fiberglass*, because it transmits the sound of the soil better. Inspectors can also use it to step over electric fences, because it does not conduct electricity. It further reduces the risk of accidentally puncturing an electrical ground cable. The probe is also less cold to the hands. By attaching a scale to the probe, inspectors can use it as a measuring stick and as a reference on inspection photos.
2. In sport fishing, *special polarized glasses/goggles* are used to see the fish better in the water. These goggles mask the reflection of the water's surface. These goggles can be used to better identify sand boils on ditch bottoms.

Figure 8.13: Examples of personal gear and instruments for inspection of flood defences

If possible and available, use:

- Drones to inspect the flood defence from above, preferably provided with infra-red sensors. The images give an overview and helpful in finding anomalies like sand boils.
- Thermal cameras, which fit easily in the jacket pocket. Thermal cameras are useful when working on flood embankments to detect excessive water seepage/piping, such as at sandboils on the land side of embankments.
- Sonar balls to check the water depth.

8.3.6 Timing of inspections and preparing the flood defence

Long vegetation or grass on slopes of flood embankments hampers visual inspection, as such vegetation covers fissures, cracks and/or other damages of the slope cover. Mowing the grass cover and removing it from the flood defence before the high water season or on receipt of an (early) warning is strongly advised.

Sometimes, during inspections in wintertime, snow cover may be present on the flood defence. Under such conditions, there are alternative strategies possible:

- Inspect immediately so that animal tracks and water seepage can more easily be observed. However extra precautions will be required to inspect safely.
- It is generally safer (less slippery conditions) and easier to observe the details of the defences after the snow has melted. In this case, it is advised to inspect the sunny slope of embankments first followed by inspections of shadowy slopes later in the day when more snow will have melted.

8.3.7 Headquarters for inspections during flood emergencies

When high-water inspection is expected, the flood defence organisation should be able to receive the findings of the inspectors by phone call, app or paper forms.

At the headquarters, the following infrastructure should ideally be made available:

- A front office manned by staff taking care of inspection tools and equipment (handing out and receiving, keeping in good condition).
- An Emergency Operations Centre (EOC) or back office with:
  - Staff operating the inspection software, tools and devices.
  - Flood defence specialists, who assess reported anomalies on a continual basis. Any urgent damage is immediately reported to them so that emergency measures can be defined and carried out.

Simple standard response measures such as sandbags and geotextiles should be prepared and brought to strategic locations prior to high-water events and any inspection.

Communicating during noisy inspections

During noisy situations, such as during severe wind conditions, inspectors may only be able to hear one another when very close (less than 2 m). Alternative ways of communicating in such a situation may include:

- Use of previously agreed hand signals.
- Use of mobile phones or other electronic means of communication – see Chapter 7.

Note that, as discussed in Chapter 7, normal communications tools such as mobile phones may not be functioning due to power failures, or the mobile network being jammed due to overuse.

8.4 Inspection and monitoring during emergencies

The purpose of flood defence inspection is to monitor the condition of the flood defence so that any potential anomalies (damages) can be identified and reported at an early stage. The aim is to identify and carry out any repairs needed to ensure the flood defence's continued functioning and to prevent any further damage from occurring. This section provides recommendations on how to inspect flood defences during high-water emergencies.

Flood embankment, Cali, Colombia

A flood embankment around the city of Cali, Colombia, protects about 1 million people. Despite its importance, there is no tradition of inspection and maintenance. Also, there is a lot of illegal construction on the flood embankments, although the responsible authorities try to prevent people from living in huts illegally. In some areas, vegetable gardens on the flood embankments are maintained by the community and they are allowed to use the produce.

Through the so-called Blue Deal contacts with Dutch Regional Water Authorities, the responsible authorities hope to improve their knowledge of flood embankment performance and failure mechanisms and to develop plans to organize inspections.

Inspections in Romania

In Romania, flood emergency situations are managed by the Joint Order of the Ministry of Environment, Water and Forests (MEWF) and the Ministry of the Interior (MOI). There are three forms of inspection:

- *Regular inspection* of hydrotechnical works with a flood defence role. This is carried out by operational staff of the River Basin Authority Water Management System (RBA/WMS) units. Annual inspections are implemented every autumn, organized and carried out by MEWF, ANAR (the national water authority) and county institutions (which fall under MOI). The focus is on vulnerable/critical areas of the defences. The inspection process also includes delivery of emergency supplies and equipment (such as sand bags – see e.g. Figure 8.14) and dissemination of flood hazard and risk maps to the population. These actions result in a plan of measures, including who is responsible for implementation. In addition, the hydrotechnical constructions of ANAR are inspected every

are inspected every autumn by teams consisting of representatives of ANAR and RBA/WMS, including the technical and functional condition of components with a flood defence role.

- *Inspection after hydrometeorological events* (flood), with focus on the technical and functional condition of hydrotechnical constructions with a role of flood defence.
- *Inspection of hydrotechnical constructions which are permanently under water* is undertaken only during the drawdown of the water levels in the reservoirs. This is usually planned to coincide with scheduled repair works.

The results of inspections provide an important basis for prioritising funding and proposed follow-up works.

Figure 8.14: Emergency response measures (courtesy: Cristian Barbu)

Monitoring conditions during a flood event in the US

Inspection of flood embankment conditions during a flood involves a multidisciplinary approach, combining engineering expertise, scientific analysis, and community engagement to safeguard lives and property against the impacts of flooding and other natural disasters. Inspectors visually assess the condition of the flood embankment, looking for signs of damage, erosion, seepage, or any other structural issues that may compromise its stability. This inspection may be conducted from ground level or aerially using drones or helicopters. There are many risks involved with inspecting a flood embankment during a severe weather event (Figure 8.15) and precautions must be taken.

Figure 8.15: Inspecting the eroding edge of a flood embankment in Startup, WA, U.S during severe weather.

8.4.1. Flood defence inspector

Flood defence inspectors are the eyes and ears of a emergency management organisation during an emergency, such as high-water events, heavy rain and storms (including severe wave action), fast drop of water level, ice conditions (rivers/lakes), drought etc. The inspectors identify, register and report anomalies (damages).

Flood defence inspection can be carried out by:

1. Flood defence inspection experts

The inspection experts are trained and experienced staff, most commonly working for the flood defence organisation.

Emergency response team flood defences, The Netherlands

The CTW (in Dutch: Crisis expert Team Waterkeringen), a dedicated emergency response team for flood defences, is a collaborative arrangement which draws in various flood defence experts in the Netherlands from Rijkswaterstaat, Regional Water Authorities, Ministry of Defence and Deltares. They can be called in for tailor made advice and assistance during a flood emergency. Members of the CTW receive special training so that they are able to assist effectively and safely.

2. Trained flood defence inspectors/not experts

A second group consists of trained flood defence inspectors. They can be volunteers, who are trained/instructed in how to monitor the flood defences and flood barriers during periods of special or exceptional circumstances. These flood defence inspectors assist the flood defence organisation by being additional eyes and ears. Their task is to draw attention to changes and deformations of the flood defence. They alert expert inspectors so that the experts can judge the seriousness of the observations and where needed identify appropriate interventions.

To maintain their inspecting skills, volunteer inspectors should be trained on a regular basis with both flood defence knowledge and how to improve personal safety. In this way, volunteers will be more confident during their inspection, especially when inspecting under severe weather conditions. These volunteers should come under the guidance, responsibility and (legal) liability of the flood defence organisation, arrangements for which should be organised during the preparedness phase (see also recommendations on health and safety in Chapter 13).

3. Public

During exceptional circumstances, it might be appropriate to involve the public in flood defence inspection. The members of the public often know their area well and can identify significant changes in the defences. If they know who to call or have the use of an inspection app, they might well provide valuable assistance to the flood defence inspectors.

App2c Inspection app for public use

The Environment Agency in England, UK, plans to make the inspection app App2C (see Section 8.4.5 for details) available for civilians to use to report a damage or breach to the Agency. Based on this information, flood defence specialists would inspect the reported situations and assess the expected performance of the flood defence.

4. Use of drones

Drones offer a useful extra means of flood defence inspection and have increasingly become more mainstream. Their advantage is that inspectors do not have to send people to a (damaged) flood defence, instead gaining a clear overview remotely by using a drone. For this, a drone operator should be trained what to look for, as reading and interpreting recorded footage takes experts' valuable time. Increasing development in AI will make this task easier. Weather conditions, the duration (battery), no-fly zones are aspects to be considered, as it is not always possible to operate a drone (see Table 8.1).

Table 8.1: Overview of remote sensing techniques available to detect various failure mechanisms

Failure mechanism	Remote sensing technique	Advantages	Disadvantages
Overtopping	Sentinel-2 Satellite	Data products are provided free of charge, resolution of 10 m in visible range. So quite accurate to detect overflow and wave overtopping.	Globe coverage 5 days
	Real time sensor	Easier to monitor with a live data feed or alarm signal with threshold. No staff needed.	Not yet available on market, high development cost. Damages need to be regularly repaired
	Landsat	Data products are provided free of charge, no staff needed because satellite based.	Repeat cycle 16 days, resolution 30 m
	SPOT	Data products are provided free of charge for the resolution of 10 m.	Repeat cycle 26 days
Macro instability innerslope	Sentinel-2 Satellite	Data products are provided free of charge, resolution of 10 m in visible range. Quite accurate to detect any damages on flood embankments.	Globe coverage 5 days
	Real time sensor - Extensometer	Real time and very accurate data. Orobe is used for monitoring the magnitude of the vertical deformation of the body or foundation of flood embankments.	Remote sensing not yet available, only the instrument. High cost to build up the instrument.
	Landsat	Data products are provided free of charge, no staff needed because it is based on satellite date.	Repeat cycle 16 days, resolution 30 m
Micro instability outerslope	Worldview-2 satellite	Repeat cycle 1.1 days. Resolution 0.5 m. Very accurate.	Costs $17/km2
	IKONOS	Resolution 0.82 m. Costs $10/km2	14 days repeat cycle
	Ground Penetrating radar	Affordable and capable to detect animal burrows underground. Very high resolution in a short amount of time	Limited range, relatively small scale Not possible to walk kilometres with the device. Needed to be quick to measure
Piping	Near-Infrared IKONOS	Resolution 0.82 m. Costs $10/km2. Piping might be detected using NIR of IKONOS because it detects temperature differences on the soil and the near water body.	Repeat cycle 14 days
	Ground Penetrating radar	Affordable and capable to detect burrows underground. Very high resolution in a short amount of time	Limited range, relatively small scale Not possible to walk kilometres with the device. Needed to be quick to measure
	Real time sensor-Ground level meter	Easier to monitor with a live data feed or alarm signal with threshold. Dike crest elevation and height and fluctuations can be identified.	Not yet available on market, high development cost. Any damage needs to be regularly repaired.
Animal burrows	Thermal Imaging Camera	Images show temperature differences very accurately and shows that holes usually have lower temperature. Size of holes or animals can be determined.	Limited range, relatively small scale, could detect anything other holes that are relatively colder than the surface but not from animal. Distortions can be detected.
	Ground Penetrating Radar	Affordable and capable to detect burrows underground.	Limited range, relatively small scale. Not possible to walk kilometres with the device. Need to be quick to measure
	Multispectral Camera	Very specific images showing differences in vegetation, wide range	High maintenance, expensive. Weather must be good otherwise drone cannot fly.

8.4.2. Flood inspection process

Flood defence inspection during emergencies entails four processes: observation, diagnosis and prognosis, followed by execution of any emergency response measures (see Figure 8.16). In the field, the inspector observes. A trained inspector may take care of diagnosis, prognosis and/or defining emergency response measures. Alternatively, based on data of the field observation, flood defence experts in the Emergency Operations Centre check the information the inspectors sent in, such as via a dashboard. Here, diagnosis and prognosis of the problem can take place, and when needed required emergency response measures can be identified here as well.

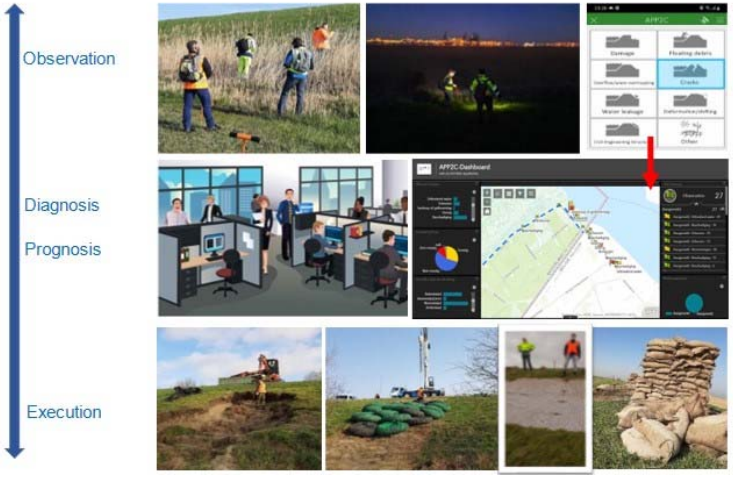

Figure 8.16: Four steps of the inspection process: Observation, diagnosis, prognosis resulting in adequate repair

8.4.3 Flood embankment inspections

Inspection of flood embankments concerns visual inspection of:

- The crest: height and state of its cover.
- The cover and alignment of the outer slope: grass, stone, and/or asphalt revetment.
- The inner slope.
- The outer and inner toes.
- Any seepage drains and the area in the flood prone area.

Visual inspection involves walking the entire length of the flood embankment and examining it closely. The inspection team should observe the flood defence inner and outer slopes, observing carefully, from different angles (see Figure 8.17) and looking for anomalies.

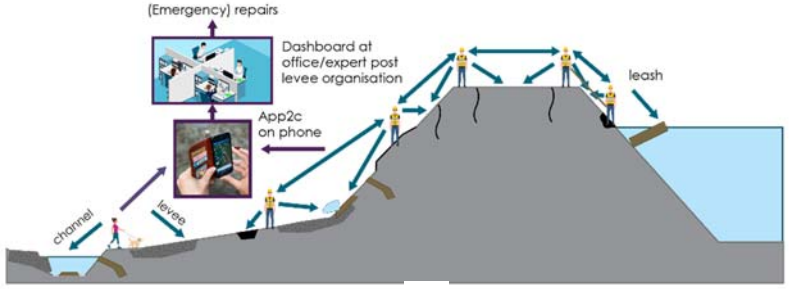

Figure 8.17: Schematic presentation of inspection of flood embankments

The following anomalies should be identified (see also Figure 8.18):

- Overflow/ overtopping.
- Erosion of waterside, crest or landside.
- Bare spots or vegetation issues.
- Animal burrows.
- Signs of seepage and piping.
- Areas of settlement, bulges or deformations, cracks in the embankment cover or the crown road.
- Problems with implementing closure of barriers within the embankment.

Figure 8.18: Overview of potential anomalies of flood embankments

Anomalies may be signs of various failure mechanisms occurring (see Chapter 9 for details of mechanisms). For example:

- Signs of embankment instability can be observed by looking globally over the slope for signs of settlement.
- Erosion of the flood defence on the water side can be observed by looking at the parts that are under water or around the waterline. Checks should be made for missing material: sand, grass, stone or rockfill.
- Inspection of the landward slopes and berm are also very important to check for any indication of internal erosion: checks should be made for seepage, sand boils and escape of sediment.

A consistent inspection process is important, especially when multiple parties are involved which may include: employees of the flood defence management organisation, volunteers and contractors. Recording of the findings in a consistent way assists this, e.g. by using a paper form or smartphone/tablet App.

In the event of an emergency, the flood defence organisation should carry out inspections of a flood embankment, maybe several times a day. Important points to consider:

- Inspect always with a team of at least 2 people (during the emergency, for personal safety and joint discussion of the findings).
- Report the start (location and time) of the inspection to the flood defence organisation. Park all inspection vehicles safely.
- A team of inspectors should walk in a line, perpendicular to the direction of travel along the embankment.
- Inspectors should always watch where their fellow inspectors are and make sure they are safe, both on the embankment and on any road.
- Look out for any anomalies in the embankment condition.

France, Baye du Somme

Baye du Somme (France) is a large rural area with a small number of inhabitants. Consequently, flood embankment inspection and maintenance have reduced resources available. This reduced capacity is compensated in a couple of ways:

- Food embankment inspectors sometimes receive help from local farmers and other stakeholders.
- Smartphone applications provide useful and real-time information in the event of an emergency, but this is only successful if there is a good connection between the flood embankment inspectors and management.

8.4.4. Health, safety and wellbeing

The personal health, safety and wellbeing (HS&W) of inspectors is paramount and of high priority. Conditions during emergencies can be hazardous and need all appropriate precautions before starting an inspection. A risk assessment, determining the hazards and executing the

safety analysis of the activities, is to be carried out prior to the actual inspection takes place. This forms part of the HS&W culture of the organisation (see Chapter 13), which includes having reminders of the commitment to safety everywhere: on invitations, in plans and guidelines, and on display throughout the organisation.

Knowing what to do if something does go wrong is very important. Next to personal wellbeing, an injured inspector implies the absence of potentially three staff for several hours (to offer help, to transport the inspector to hospital, etc.), thereby hampering the inspection process. However, the starting point must always be prevention of HS&W problems. Prevention encompasses four focal points:

1. Prepare to inspect safely and to be able to leave quickly

   When experts or volunteers inspect the flood defence during emergencies, it is important to assess the situation and to be prepared:

   - Working alone should be avoided (see Figure 8.19).
   - In a team, there is only one leader. The team should stay together, under all circumstances (see Section 8.4.3).
   - Communication should be organised (see Chapter 7 for details) and it should be clear how the team can call for assistance (e.g. phone or help button).
   - The quickest way to get off the flood defence or out of the area should be known prior to starting the inspection. The inspection vehicle should be parked in such a way that the inspectors can leave quickly.
   - The right PPE equipment, such as safety vests, rope etc should be available and be worn/utilized.

Figure 8.19: Working in a team while inspecting the flood defence during high water

2. Be prepared for accidents that can occur at night or under harsh weather circumstances

   - Flood defence inspections that are done by walking on or alongside the flood defence, may meet with difficult conditions, especially when in the dark and in rain and storm. Conditions on the slopes and inspection routes will sometimes be wet and slippery (see Figure 8.20). When an accident occurs in these conditions, offering aid is difficult. It also means that for a prolonged period (hours), 2 or 3 staff cannot be involved in the inspection as they will need to provide help to their colleague.
   - A toolbox meeting and execution of a last-minute risk assessment (LMRA) at the start of an inspection helps to prepare and address the level of risk.
   - Instructions refer to the advice to wear life jackets and ropes in addition to wearing fluorescent safety vests.
   - Each day, one person should be in charge of assessing risk levels and maintaining a critical overview of the site situation and conditions

throughout the day. When needed, this individual should take appropriate action to ensure the safety of all inspectors.

- To be prepared for the situation when an accident does happen, it is essential to know:
  - How to use first aid kits.
  - The location of emergency routes and nearby emergency services and hospitals.
  - How to call for rescue.

Figure 8.20: Slippery and wet surface under storm conditions

3. Compliance with the requirements of the contractor

- When emergencies occur on flood defences that are under construction, most commonly the contractor is responsible for carrying out inspections.
- If not, inspectors should comply with the contractor's demands: including obtaining permission to enter the site, being safe by wearing personal protective equipment (high visibility jacket, safety shoes, hardhats, etc). All inspection activities must be communicated with the contractor to ensure that the contractor is not carrying out work on the flood defence at the same time as an inspection.

8.4.5 Identification of anomalies and role of inspection apps

It is recommended to monitor and document observations and potential issues, and to take photos and videos to document any areas of concern. This documentation can help track any changes and provide evidence of potential issues that require immediate attention. Inspections should not only identify new anomalies, but also monitor previously identified and recorded anomalies (are they getting more serious) and check whether emergency measures have been put in place.

Previously identified anomalies should include those identified during regular (i.e. non-emergency) inspections. Ideally during these routine inspections, inspectors should highlight in the database any observed anomalies that could pose a threat during a flood (so-called attention points). Inspectors should check these points where necessary and discuss them with flood defence experts. Then, for an inspection during an emergency, a filter can be used so that only these points are visible to the inspectors on the ground and they are not distracted by the less relevant points.

Information on anomalies (width, depth, exact location) can be filled in on a paper form (to be handed in after the inspection), or through an inspection app (preferably with an online connection with the Emergency Operations Centre). Use of an inspection app that allows photographs to be directly entered indicating observed damages (both close-ups and from a farther distance) is strongly advised (see examples). The dimensions and orientation of the damage should be recorded as accurately as possible. For standardization of observations, including or linking to information contained in flood defence condition catalogues (e.g. Environment Agency Condition Inspection Manual, Netherlands Digigids) will be helpful.

If an anomaly is found:

- It should be reported immediately to the experts in the Emergency Operations Centre, especially if the situation is urgent, using phone or the inspection app.
- Experts should assess the urgency of the reported anomaly on a continual basis and identify whether any emergency measures should be carried out.

Figure 8.21 shows the relationships between all relevant aspects used in this chapter and the chapters 9 and 10 in this handbook. See Figure 9.2 for a larger display of this figure.

Inspection Issues discussed in Chapter 8	Issue may indicate numbered failure mechanisms - see subsection(s) 9.2.x
Overflow/overtopping evidence	1, 2, 11
Surface erosion/bare spots	2, 3, 4
Vegetation growth/decline	2, 4, 7, 11, 13
Animal burrows	2, 3, 4, 7
Seepage (soft/wet areas)	3, 4, 11
Sand boils	4
Cracks	4, 5, 6, 7, 8, 12, 13
Bulges or deformations	4, 5, 6, 7, 8, 12, 13
Lowered spots	3, 4, 5, 6, 7, 8, 12, 13
Barrier closure problems	10, 14
Signs of structural failure	13, 14
Blockage of flow channels	14

Subsection 9.2.x	Failure mechanism	Address using emergency measure Section 10.x
1	Overflow and wave overtopping	2, 3
2	Surface erosion	3, 5
3	Internal erosion	3, 4, 5
4	Backward erosion piping	3, 4, 6
5	Liquefaction	6, 7
6	Settlement	2
7	Landside slope instability	3, 4
8	Waterside slope instability	3, 4
9	Failures at transitions	2, 3, 4, 5, 6
10	Untimely gate opening/closing	3, 6, 7
11	Excessive leakage/flow	3, 5, 6
12	Block sliding/overturning	3, 4
13	Structural failure	3, 4
14	Flood diversion failures	3

Subsection 10.x	Emergency measures
2	Raising defence crest
3	Reducing load
4	Strengthening the defence
5	Erosion protection
6	Emergency embankment
7	Breach closure

Figure 8.21: Locations of flood defence aspects in the Handbook

1-2-3 Service App used in the US

In the United States, inspectors use a streamlined 1-2-3 phone and tablet-based application (see Figure 8.22) which allows flood responders/inspectors to submit geo-referenced observations and reports from the field to a single database at the Emergency Operations Centre (EOC). It allows for very rapid assessment of field conditions, and quickly and efficiently transmitting them to the EOC. This is very important, as timely response in a flood event can make a big difference.

The 1-2-3 tool is an accurate and efficient way of capturing information during a flood response. It also allows any duplicate information to be recognised, assisting direction of response effort where it is needed.

The app is easy to install, use and navigate. Set up on a phone takes just a few minutes after which the inspector is ready to start collecting information. The app already contains a database of flood embankments, saving time and effort. Taking photos can be done through the app, eliminating the need for texting and emailing photos separately.

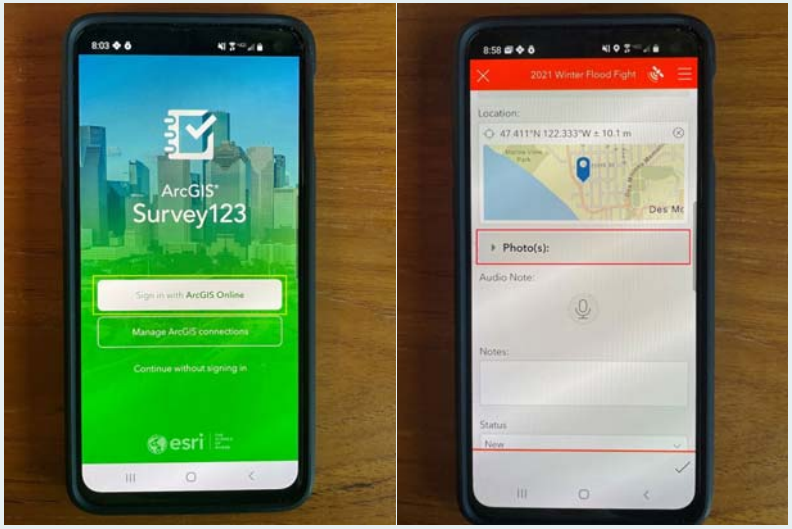

Figure 8.22: 1-2-3 Service app

App2C inspection app

In the framework of the EU Interreg project Polder2Cs (Booltink, 2023) the inspection app App2C was developed. In the field, the inspector can enter the information of observed anomalies on a mobile device. The app is online, so that any information entered is immediately available to flood defence experts in the back office (see Figure 8.23).

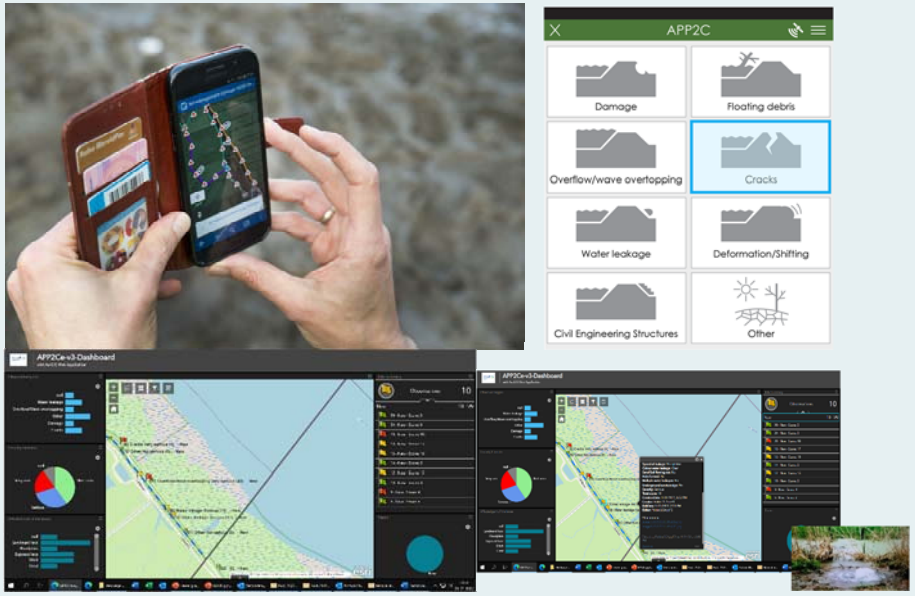

Figure 8.23: Screen dumps from the App2C inspection app

The App2C dashboard is a graphical user interface that gives an immediate overview of any entries. All deterioration/damage reported from the field can be filtered for status (new/to be monitored, etc), status, damage type, severity, affected part of the flood defence. The photos sent in the App2C are also visible in the dashboard.

In the Emergency Operations Centre, flood defence experts can use this information to diagnose and prognose the severity of the reported damage for the performance of the flood defence and assess whether emergency measures are needed. A calculated emergency score helps to set priorities.

8.4.6 Using results of inspections to prioritise interventions

During an emergency, several anomalies indicating damage may be reported at the same time. It is important to prioritize responses to these reports, as implementing the required actions (repair, emergency response) may not be possible instantly (e.g. shortage of time, staff, equipment). Prioritizing responses to the most dangerous damage with highest impacts is therefore essential. Less severe damage with lower priority can be monitored by planning follow-up inspections as a substitute to immediate repair (see example in Table 8.2).

For flood embankments, the types of damage for which response may need to be prioritised include:

- Direct instability.
- Crests which have settled too low.
- Fast degradation of the inner body of the embankment.
- Damage which is close to the water line and is expected to increase rapidly by erosion.
- Any larger damage (e.g. based on size and depth of a subsidence or crack).

Other factors influencing the priority of any response include:

- The possibility of immediate quick repair to prevent further damage.
- The time needed to carry out the repair; if the repair is complex it may need to be scheduled earlier.

Priority setting should ideally be the responsibility of the Emergency Operations Centre (emergency operations room of the flood defence organisation), which will have a sound overview of the actual changes in performance of the flood defence system under the emergency conditions. Prioritization should be based on some form of risk assessment, carried out by flood defence experts who understand the flood defence, the risks involved and the kinds of repairs that can be executed under emergency conditions.

Table 8.2: Practical priority setting for flood embankment damages (Regional Water Authority Rijn and IJssel)

Damage	No priority: No report	Low priority: To be reported	High priority: Report immediately
Slope instability	---	---	Observed slope instability
Floating debris	No damage	Minor damage, no immediate threat	Major damage, acute threat for flood embankment
Wave overtopping	---	---	Observed wave overtopping
Overflow	---	---	Observed overflow
Failure of structure	---	---	Observed failure
Digging inland slope	Depth < 0,15 m	Depth 0,15 – 0,30 m	Depth > 0,30 m
Damage grass cover	Inner slope: bare spot/ missing grass sod < 0,3x0,3 m	Inner slope: bare spot/ missing grass sod > 0,3x0,3 m	• Outer slope: Grass sod missing • Inner slope: larger area grass sod missing + high risk of overflow
Damage stone revetment	---	---	Report missing elements
Crack in paved crest in length of embankment	Existing cracks	Existing cracks, increasing length	• New cracks, with b > 0,1 m • Existing cracks with increasing length + increasing width > 0,01 m
Crack in crest or slope with no hard caver	---	---	• New cracks • Existing cracks with increasing length + horizontal or vertical movement > 0,05 m
Water seeping out embankment	---	---	Report immediately
Deformation of adjacent hinterland	---	---	Movements, crack formation in flood embankment and/or adjacent hinterland
Sandboils	---	Always report	More than 10 ltr of sand (one bucket) and/or more than 2 sandboils in 5 x 5 m^2

8.5 References

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CHAPTER 9

Understanding the problem

Key messages:

- **Understand how flood defences fail**
- **Trained inspectors can identify potential failures**
- **Defence fragility curves help prioritise action**

Figure 9.1: Structure of the handbook

Other places to find information on the topics of this chapter

Chapter 5: Types of threats to be considered in emergency planning

Chapter 6: Overview of flood defence types subject to failure during emergencies

Chapter 8: Procedures for detecting early signs of failure and visual inspection clues for inspectors

Chapter 10: Techniques for implementing emergency measures to stabilize flood defences

Chapter 11: Selection of response measures based on specific failure modes and logistical constraints

Chapter 14: Understanding of overall process and reliability of the process, including in relation to failure mechanisms and fragility curves

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Note:

The Reader is kindly requested to take note of the Disclaimer on page ii of this handbook.

Chapter title page photograph:

Sand boil (courtesy: USACE)

Key messages:

- **Understand how flood defences fail**. To effectively address flood risks in extreme events, it's crucial to understand how and when a flood defence may fail. This knowledge forms the basis for formulating and correctly implementing emergency interventions.
- **Trained inspectors can identify potential failures**. The ability of on-the-ground inspectors to visually identify clues plays a pivotal role in predicting potential failures of flood defences. The better equipped emergency personnel are at recognizing these indicators, the greater the likelihood of successful intervention strategies.
- **Defence fragility curves help prioritise action**. Utilising fragility curves provides valuable insights into the probability of specific failure mechanisms, enhancing the forecasting of failures in an emergency response context and assisting in prioritising emergency interventions.

The sections of this chapter discuss the following:

- Section 9.1 – an overview of failure mechanisms, including their relationships to various structure types (Chapter 6), inspection issues (Chapter 8) and mitigation measures (Chapters 10 and 11).
- Section 9.2 – individual failure mechanisms and an overview of their mitigation.
- Section 9.3 – creation and use of fragility curves to describe defence performance.
- Section 9.4 – the process of flood embankment breach and the options for slowing or stopping the breach at various stages.

9.1 Overview of failure mechanisms

By its function, a flood defence is a means to prevent flood waters from flowing from one side to the other. In essence, a flood defence consists of one or more barriers and a supporting structure designed to exclude floodwater. Failure happens when one of these elements becomes dysfunctional.

A failure mechanism is the way that dysfunctionality occurs, either by leakage or by loss of support, either inside the flood defence itself or in its foundation. Ultimately, this leads to flooding of the protected land, unless the flood conditions recede or measures to strengthen or replace the defence are taken. Table 9.1 shows the relationship between the failure mechanisms discussed in this chapter and the types of flood defences discussed in Chapter 6.

Table 9.1: Applicability of various failure mechanisms to different types of flood defence

Failure mechanism (Note: √ = applies)	Embankment	Flood wall	Demountable / Temporary defence	Ancillary closure structure	Control lock, weir	Flood detention structure (dam)	Pump/pipeline	Flood diversion channel	Load reduction system
External erosion due to overflow and/or wave overtopping (S 9.2.1.)	√	√				√		√	√
Surface erosion (water and land side) (S 9.2.2)	√	√				√			
Internal erosion generally (S 9.2.3)	√			√	√	√	√	√	√
Backward erosion piping (S 9.2.4)	√	√		√	√	√			
Liquefaction (S 9.2.5)	√	√		√	√	√		√	√
Settlement (S 9.2.6)	√	√	√	√	√	√	√	√	√
Landside slope instability (S 9.2.7)	√					√			√
Waterside slope instability (S 9.2.8)	√							√	√
Embankment / hard structure transition failure (S 9.2.9)		√	√	√	√	√	√	√	√
Untimely gate closure (S 9.2.10)				√	√			√	√
Excessive leakage /flow through hard structure (S 9.2.11)			√	√	√				
Block sliding or overturning (S 9.2.12)		√	√	√	√	√			
Structural failure (S 9.2.13)		√	√	√	√	√			
Flood diversion failure (S 9.2.14)							√	√	

The art of flood defence emergency response lies in:

- Timely detection of signs of upcoming failure (Chapter 8).
- Understanding the various ways failure may occur (this chapter).
- Applying effective response measures to prevent failure from happening or continuing (Chapter 11), using techniques such as those described in Chapter 10.

Figure 9.2 provides a more detailed overview of the steps that should be taken to determine the appropriate response:

1. During inspections (see Chapter 8) of different types of flood defence (Chapter 6), anomalies should be identified (see Section 8.5).
2. The information about anomalies should be transferred to flood defence experts with geotechnical, structural and hydraulic expertise, who interpret this information using the knowledge provided in this chapter. (For example, signs of “surface erosion / bare spots” in Chapter 8 may be related to surface erosion (Section 9.2.2), internal erosion (9.2.3) or backward erosion piping (9.2.4)).
3. The relative importance of the damage and the need to take emergency measures should ideally be assessed using fragility curves, as explained in Section 9.3.

Taking account of logistical constraints, an appropriate emergency response should be chosen, as detailed in chapter 10. (For example, in the case of backward erosion piping (see section 9.2.4), following the logic in Figure 9.2, the emergency response may consist of reducing load (see Section 10.3), strengthening (see Section 10.4) or erecting an emergency embankment (see Section 10.6).)

Inspection Issues discussed in Chapter 8	Issue may indicate numbered failure mechanisms - see subsection(s) 9.2.x
Overflow/overtopping evidence	1, 2, 11
Surface erosion/bare spots	2, 3, 4
Vegetation growth/decline	2, 4, 7, 11, 13
Animal burrows	2, 3, 4, 7
Seepage (soft/wet areas)	3, 4, 11
Sand boils	4
Cracks	4, 5, 6, 7, 8, 12, 13
Bulges or deformations	4, 5, 6, 7, 8, 12, 13
Lowered spots	3, 4, 5, 6, 7, 8, 12, 13
Barrier closure problems	10, 14
Signs of structural failure	13, 14
Blockage of flow channels	14

Subsection 9.2.x	Failure mechanism	Address using emergency measure Section 10.x
1	Overflow and wave overtopping	2, 3
2	Surface erosion	3, 5
3	Internal erosion	3, 4, 5
4	Backward erosion piping	3, 4, 6
5	Liquefaction	6, 7
6	Settlement	2
7	Landside slope instability	3, 4
8	Waterside slope instability	3, 4
9	Failures at transitions	2, 3, 4, 5, 6
10	Untimely gate opening/closing	3, 6, 7
11	Excessive leakage/flow	3, 5, 6
12	Block sliding/overturning	3, 4
13	Structural failure	3, 4
14	Flood diversion failures	3

Subsection 10.x	Emergency measures
2	Raising defence crest
3	Reducing load
4	Strengthening the defence
5	Erosion protection
6	Emergency embankment
7	Breach closure

Figure 9.2: Connections between chapter 8, 9 and 10 of this handbook

A better understanding of the various ways in which a flood embankment may fail, should help to avoid failure more effectively and minimize adverse effects from the emergency measures taken.

In the remainder of this chapter:

- Section 9.2 describes the most common failure mechanisms in more detail. Nine of these are related to earthen flood embankments. In addition, four rather generic failure mechanisms of other types of flood defences are described briefly, as well as the loss of flood diversions.
- Section 9.3 describes fragility curves as a powerful tool to gain insight in the most important threats at increasing water levels. These curves are derived from an understanding of various failure mechanisms and can be updated over time, to reflect improved information, survived loads and the effect of emergency measures.
- Section 9.4 describes breach formation and the (limited) opportunities still available at that stage. All failure mechanisms may eventually lead to breaching, if not averted and the flood event continues.

9.2 Failure mechanisms

This chapter focusses on failure mechanisms for flood embankments, arranged by the main cause of failure (Kortenhaus, 2003; CIRIA, 2013):

- Hydraulic failure mechanisms pertain to the movement of water across the structure: overflow and wave overtopping (detailed in Section 9.2.1).
- Geohydraulic failure mechanisms involve the movement of material from the flood embankment's cross-section or subsurface by flow: surface erosion (Section 9.2.2), internal erosion – sometimes known as general piping (Section 9.2.3), backward erosion piping (Section 9.2.4) and liquefaction (Section 9.2.5).
- Geostatic failure mechanisms are linked to movements of bodies, either slow processes leading to settlement (Section 9.2.6), or mass instability, either on the landside (Section 9.2.7) or on the waterside (Section 9.2.8).
- Failures at transitions with hard structures (Section 9.2.9) which can relate to any of the above mechanisms.

In addition, the chapter discusses four failure mechanisms of non-earthen flood defences:

- Delayed closures or openings of gates in structures (Section 9.2.10).
- Excessive leakage or flow through a structure (Section 9.2.11).
- Block sliding of a structure (Section 9.2.12).
- Structural failure in general (Section 9.2.13).

Finally, brief attention is given to flood diversions (Section 9.2.14).

9.2.1 Overflow and wave overtopping

Once the water level gets too high with respect to the height of the flood embankment, water will flow over the crown, first by overtopping waves (if present) then by overflow once the water level becomes higher than the crest (Figure 9.3 and Figure 9.4, respectively).

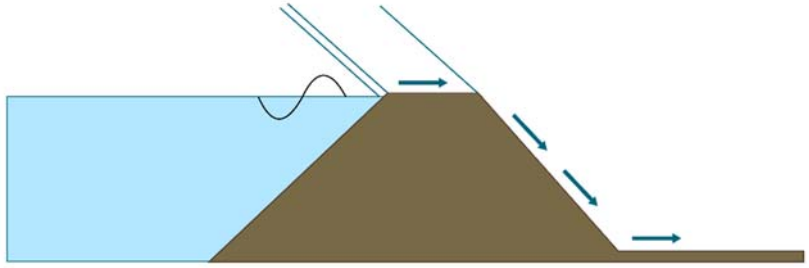

Figure 9.3: Wave overtopping

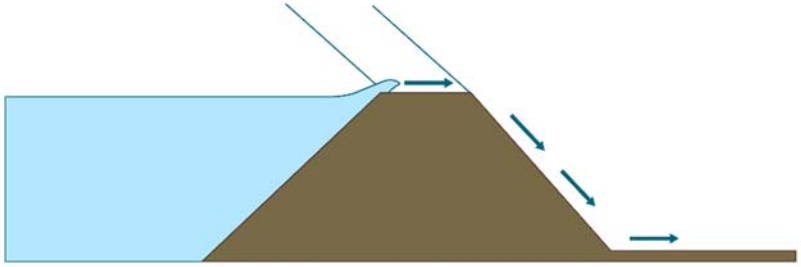

Figure 9.4: Overflow of water over the crest

Disregarding the integrity of the flood embankment, excessive severity or prolonged overflow and wave overtopping conditions will lead to flooding of the hinterland. The International Levee Handbook, Sections 8.2.1.5 and 8.2.2.1, gives guidance on the overtopping discharge for various configurations (CIRIA, 2013). Whilst overflow and wave overtopping are not in themselves failures of the structure of the earth embankment, they will advance other failure mechanisms of the embankment structure, especially surface erosion, landside slope instability, general piping, and breach formation.

This mechanism, and its consequences, may be prevented or reduced in magnitude by raising the effective height of the flood embankment by placing materials on the crown. Perfect watertightness is not required for the defence raising, although it is important to avoid unintended negative consequences. Applying too much quantity/weight of material and equipment (such as vehicles) can cause instability or rapid settlement. This instability and/or settlement is most likely when significant amounts of soft, saturated materials like clay or peat are present in the flood embankment or its foundation. Attention should also be paid to the stability of the measures themselves: they should not be pushed or washed away by waves, nor overturn. More details are given in Chapters 10 and 11.

9.2.2 Surface erosion

Currents and waves will exert a shear stress on the surface of the flood embankment. These shear stresses are increased by any irregularities already existing on the surface of the flood embankment; such irregularities may result from factors such as burrowing animals or abuse of the flood embankment as a source of construction materials. Once the critical shear stress of the material is exceeded, material will be eroded. This further increases the irregularity of the surface, causing an increase in the forces exerted by the currents and waves and a further increase in the erosion. Moreover, materials underneath the original surface may be less resistant to erosion.

Currents and flows that may cause erosion may be distinguished according to (see Figure 9.5):

- Waterside slope:
  - Currents along the flood embankment (see Figure 9.6 for an example of resulting damage).
  - Wave flows acting on the slope:
    - Upward flow.
    - Downward (returning) flow.
  - Flow across the flood embankment.
- Landside slope:
  - Downward (non-returning) flow only.

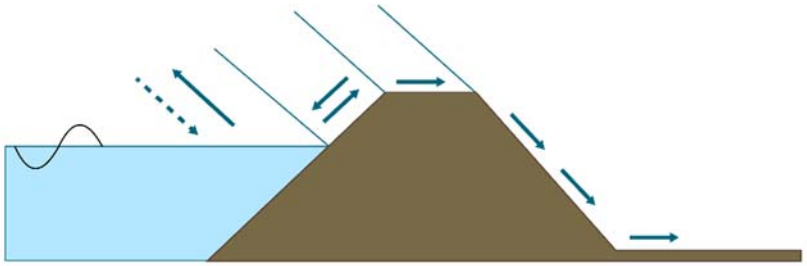

Figure 9.5: Surface water flows in various directions that may cause erosion

Figure 9.6: Erosion on the waterside of a dike along the Maas River in the Netherlands, 21 May 2012 (source: Deltares)

With impending (severe) flood conditions, emergency measures to prevent surface erosion should ideally be taken before the flood arrives. (Apart from surface erosion, many other failure mechanisms will also then become more unlikely to occur.) Solutions for temporary protection of the surface with a wide variety of materials and conditions are discussed in the international Levee Handbook (CIRIA, 2013 – Chapter 6). Note that most of the surface protection measures discussed in Chapters 8 and 9 of the International Levee Handbook are intended for use in design and construction, or assessment of the strength of an existing well-maintained flood embankment.

During flood conditions, deep scouring of flood embankments should be prevented from further development. This may be achieved by placing elements upstream to reduce flow velocities, or by covering the (potential) weak spots with weighted down sheets of impermeable or permeable material. Priority should be given to avoid erosion of the crown and landward face of the flood embankment.

9.2.3 Internal erosion

The outflow of particles from inside the body of the flood embankment is generally described as internal erosion. Characteristic forms of appearance are concentrated leak erosion, suffusion, and contact erosion. In all these cases, flow of water through the flood embankment is large enough to cause the detachment of particles. This is then followed by transport of these particles in combination with the creation of voids that are strong enough to let the particles pass through. An example is shown in Figure 9.7.

Figure 9.7: Failure of a test embankment at the IJkdijk by internal erosion leading to breaching, 27 August 2012 (courtesy André Koelewijn)

Concentrated leak erosion occurs along crack openings or pre-existing holes like animal burrows, as indicated in Figure 9.8. In case of suffusion, the smaller particles are transported through the pores in the matrix of larger particles. This requires a significant variation in grain size. Contact erosion may occur at the interface of a coarse layer and a fine layer. Clear guidance on these erosion mechanisms is given by ICOLD Bulletin 164 (ICOLD, 2017). These mechanisms should ideally be avoided by addressing them during design and construction of a flood embankment.

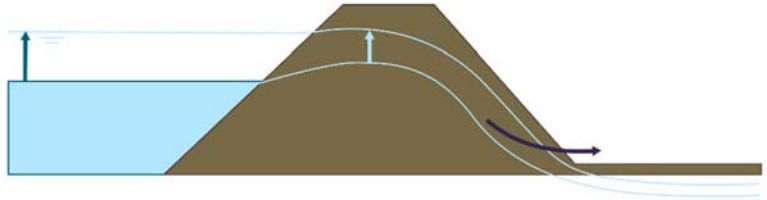

Figure 9.8: Concentrated leak erosion from an animal burrow when the water level and the groundwater table are raised by a flood

Effective emergency measures against such internal erosion are rather difficult to take, once either of these mechanisms occur (ICOLD, 2017). Two options that may be applied to flood embankments, both requiring significant effort, include:

- Application of a reverse filter. A reverse filter requires a graded filter with the largest particles towards the surface; by having particles too heavy to be eroded located at the outer surface, this prevents small particles escaping and yet allows water flow. For this solution, knowledge of the required particle size is required, as well as suitable materials in sufficient amounts.
- Construction of a weighting berm. Although this is close to building a second flood embankment, it might be the most suitable option to avoid a breach.

9.2.4 Backward erosion piping

Unlike the other forms of internal erosion described in the previous section, backward erosion piping occurs in the sand layer in the foundation underneath the flood embankment itself and beneath any cohesive foundation layer. The head difference across the flood embankment causes seepage flow through the sand layer and the mechanism starts when this seepage flow is strong enough to erode grains from this sand

layer on the landside of the flood embankment. This is usually visible as a sand boil (see Figure 9.9) at the exit point.

Figure 9.9: Example of a sand boil resulting from backward erosion piping (courtesy: André Koelewijn)

When the head difference increases, a small flow channel will develop underneath the flood embankment and grow towards the waterside. The mechanism is named after this backward growth process, see Figure 9.10. Typically, an equilibrium is reached at which the sand boil does not produce any more sand. However, if the head difference exceeds the critical head, then the small flow channel with grow further. It will ultimately reach the waterside and increase in size over the full length, resulting in a flow of sediment at the exit point. This is generally followed by partial collapse of the flow channel, lowering of the crown and breach formation. The critical head depends on the properties of the sand and the overall geometry; guidance on how to determine the critical head are given in ICOLD (2017) and Section 8.5.1 of the International Levee Handbook (CIRIA, 2013).

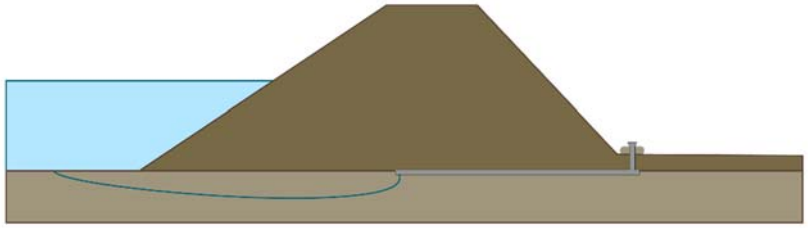

Figure 9.10: Schematic of backward erosion piping, at a stage when the critical length of the pipe is typically exceeded (note that the size of the piping channel [underneath and through the blanket layer] is strongly exaggerated in this figure)

If the sand layer is covered by a blanket layer of other material at the landside, like a clay deposit or a peat layer, the mechanism should not occur because the sand grains cannot be transported to the ground surface. However, reasons why the mechanism still progresses in practice are as follows:

- If the blanket layer is of several metres thickness, uplift of the layer will be required for this mechanism to occur. However, uplift can occur if the pore pressure in the sand layer to exceeds the weight of the blanket layer. In addition, if a ditch or a larger body of water is present on the landside, the thickness of the blanket layer will also be less, increasing the likelihood of the mechanism occurring.
- If the blanket layer is less than 1-2 metres in thickness, existing cracks may well be present through which the sand grains can escape and initiate the mechanism. These cracks may arise from the general structure of the soil or from shrinkage during dry periods.

If a sand boil commences, it is not necessarily fatal, because there is a margin in the head difference at which the first particles will exit, and the critical head. However, once the critical head is exceeded, the exact timing of failure is difficult to predict because:

- Failure of the flood embankment may take several hours to days, requiring the erosion flow pipe to grow to the waterside of the flood embankment and to increase in size.
- The transition from below to above the critical head cannot be observed by phenomena at the landside exit point.
- The erosion pipe reaching the waterside does not lead to any clear change at the landside exit point either.

However, a progressive change from a stable, sediment rich, flow into a kind of mudflow at the exit point is a clear warning sign of imminent failure. The flood embankment will then typically breach in less than 15 minutes.

Emergency measures to counter this failure mechanism include either

- Reduction of the overall head difference below the critical head by measures on the landside. Possibilities for increasing the landside water level strongly differ on the local situation. Sometimes placing sandbags is the best option, in other cases blocking the drainage of a ditch will be the most effective solution, and many more solutions exist. Note that placing a pile of sandbags around a sand boil may result in a new sand boil to occur a short distance away from the initial boil. In any event, once the erosion pipe has exceeded the equilibrium length associated with the critical head, a further general reduction of the head difference will generally be required to avoid failure.
- Preventing the sand grains escaping. This can be achieved by placing a suitably coarse-grained filter or installing a permeable geotextile around the exit point.

9.2.5 Liquefaction

Liquefaction refers to the sudden loss of strength in loosely packed, saturated soils due to excess pore water pressure caused by shear loading, typically from shaking or rapid loading. The most extreme example is of spherical grains, in the loosest packing possible. Small deformations lead to excess pore pressures and to loss of shear strength, quickly escalating into failure of the volume in the form of a high-density liquid.

Liquefaction (see Chapter 8 of CIRIA, 2013) is typically associated with earthquake loading and may cause significant lowering of the flood embankment and other damage (Figure 9.11). However, so-called static liquefaction may occur in areas with loosely packed sand deposits and no history of earthquakes (De Groot et al., 2023). It appeared also to be the most likely cause of the failure of Edenville Dam, after almost 100 years of operation (Williams & France, 2023). The phenomenon occurs rather suddenly and may easily lead to a breach in a flood embankment.

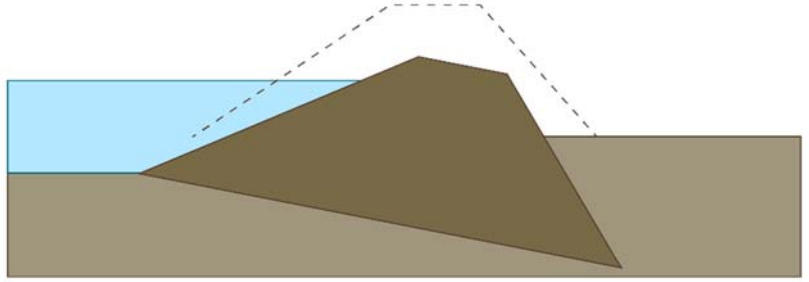

Figure 9.11: Simplified schematic of a cross-section of a clay embankment after liquefaction of the sandy foundation (original embankment profile indicated by dashed lines)

In a tidal area, static liquefaction will generally occur during the falling tide. A section of the flood embankment may be completely lost, yet flooding does not take place immediately because the water level has dropped too low. However, on the next flood tide, the water will flow freely through the opening in the flood embankment, unless emergency measures are taken. This may also happen in case of a modest flood tide without a storm surge.

As a response, an emergency embankment needs to be raised in 4 to 8 hours that is at least capable of withstanding the next high tide. This may be an earthen embankment around the opening, on the landside of the original line of the flood embankment, with the surrounding land serving

as a borrow pit for the emergency embankment material. Full realignment and reconstruction of the flood embankment can be delayed until a later stage.

9.2.6 Settlement

With time, a flood embankment will settle because of the increased stresses in the subsoil. This leads to (vertical) settlements under and nearby the structure, and horizontal deformations near the perimeter of the structure. Settlements can be categorized into:

- Immediate settlement (occurring during construction).
- Primary consolidation (dissipation of excess pore pressures, most notably in clay and peat).
- Creep (ongoing settlements, especially in clay and peat, slowing down over time).

Over time, consolidation and creep lead to a gradual decline of the crest height (Figure 9.12), and thus to an increased probability of flooding (assuming no other changes take place). Because settlements will not be uniform along the length of the embankment, low spots in the level of the crest will arise, resulting in sections of the embankment where overflow / overtopping (see Section 9.2.1) will occur first. Preferential overtopping at such unplanned locations may lead to undesirable consequences.

Emergency measures to counteract other failure mechanisms, especially those involving the placement of weight on the crown, will lead to immediate settlements and a loss of height, as well as cracking. Cracks will facilitate inflow of water and a rapid raise of the groundwater table inside the embankment. Unnecessary loads on the flood embankment should therefore be avoided, even if there is no issue with slope instability.

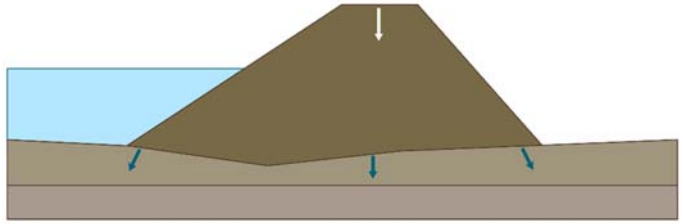

Figure 9.12: Settlement of a flood embankment

9.2.7 Landside slope instability

The steepness of the slope of a flood embankment is limited by the shear strength along any potential sliding surface, see Figure 9.13. For any conceivable sliding plane, equilibrium is required with the driving gravity force.

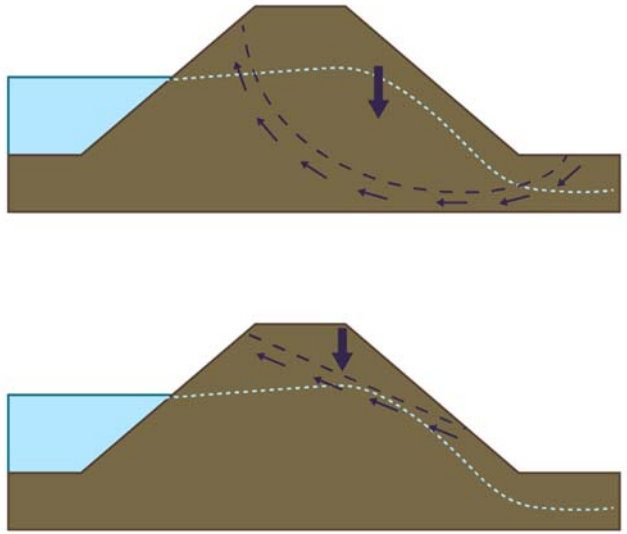

Figure 9.13: Landside slope instability: some examples of sliding planes (Indicated by a dark blue dashed line in each figure)

An increased water level on the waterside will influence the water table inside the flood embankment, see Figure 9.14 and Figure 9.15. The increase of the phreatic surface may cause instability of the landside slope by both an increase in the weight of the soil and a reduction of the effective stresses. There are many methods to analyse the stability of a slope; an overview is given in Chapter 8 of the International Levee Handbook (CIRIA, 2013).

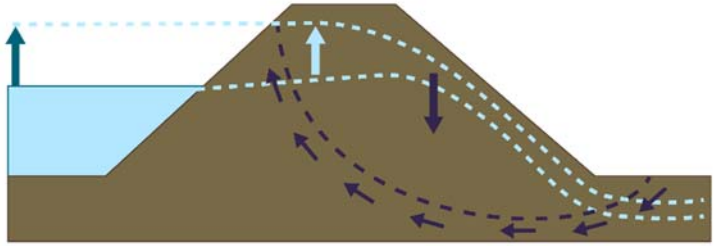

Figure 9.14: Landside slope instability: influence of raised water level

Figure 9.15 Landside slope instability failure of the Westfriese Zeedijk near Sint Maarten, The Netherlands, 15 September 1994 (source: Deltares)

If a flood emergency occurs, signs may indicate a loss of stability, such as bulging of the surface and cracks along the surface edges of a (three-dimensional) sliding volume.

In addition, measures taken to temporarily raise the crest level to reduce overflow/ overtopping may have undesirable consequences for stability. Placing weight on the crown should be avoided as much as possible. However, to reduce overtopping or even overflowing water, placing sandbags is generally still a good idea. In case of doubt regarding the stability of the slope and the required additional height is limited, sandbags are to be preferred over big bags to limit the additional weight. Moreover, the use of heavy equipment on the crown of the flood embankment to put emergency measures into place should also be avoided in such a case.

In response it is important to take appropriate actions and avoid further promoting slope instability. Measures that may be considered are:

- Improve drainage of the body of the flood embankment. This is often difficult to achieve in the short term.
- Adding weight in the form of a berm on the toe of the flood embankment, thereby supporting the lower part of the slope. However, this requires a significant amount of material to be placed and to reduce the volume to be placed dense materials are generally preferred. Good drainage of the new material is important, to avoid increasing pore pressures and reducing the shear strength along the actual or potential shear plane.

9.2.8 Waterside slope instability

In case of a rapid decrease of the water level after a flood, the slope may fail towards the waterside while the phreatic line inside the embankment is still high. Such a rapid decrease may for instance be caused by a nearby breach (which may be in the opposite bank). The principles and calculation methods are similar to landside slope stability (Section 9.2.7), but the direction of the failure is different (see Figure 9.16). Also, the immediate effects may be less, as the water level will already be lowered significantly. Yet, repairs are required before high water conditions return. This aspect is especially important in tidal areas and similar to the situation after liquefaction has occurred (Section 9.2.5).

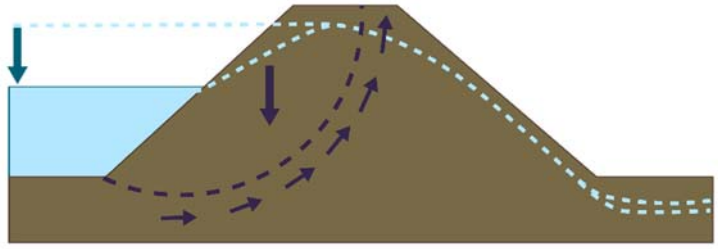

Figure 9.16: Waterside slope instability induced by a sudden drop of the water level

9.2.9 Failures at earth embankment/hard structure transitions

Transitions between earth embankments and hard structures (e.g. floodwalls or closure structures) can be points at which failure mechanisms can occur preferentially. The types of mechanisms that can occur include:

- External / surface erosion of embankment slopes (see Section 9.2.2), which increases at any transitions where there is increased turbulence due to changes in the geometry between the embankment and the hard structure. The turbulence causes scouring of the embankment if the slope protection is inadequate. The erosion may arise on the water side and, if the embankment is overtopped, on the land side as well.
- Internal erosion, especially at cracks at interfaces between earthen structures and hard structures allowing seepage and concentrated leak erosion (see Section 9.2.9).
- Differential settlement (see Section 9.2.6), which can result from unequal consolidation of soft foundation soil at the transition between a relatively heavy embankment and a relatively light concrete floodwall or closure structure. Such differential settlement can locally increase the rate of overtopping (Section 9.2.1) and encourage failure by surface erosion (Section 9.2.2) of the land side of the embankment.

Emergency interventions to mitigate problems at transitions include:

- Temporary protection of the embankment surface to limit surface erosion.
- Temporary raising of the crest of the embankment to limit overflow/overtopping.

9.2.10 Untimely closure or re-opening of gates in structures

Structures in flood defences often have gates, for example in case of a conduit or a sluice. If these are not closed in time or re-opened when required (Figure 9.17), this will worsen (potential) flooding conditions on the protected side.

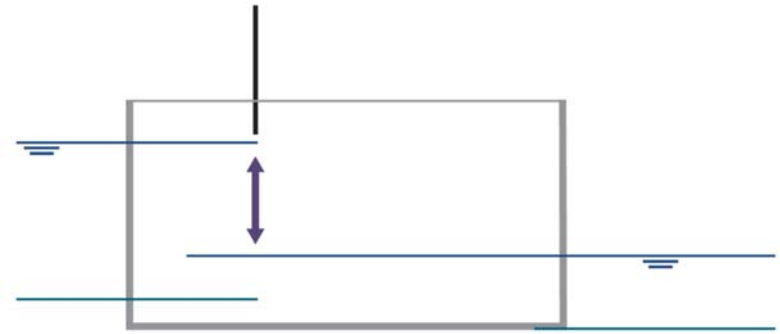

Figure 9.17: Gate closure issues

Emergency interventions for failures in closures will be as diverse as the variety of structures that may exist. However, before any emergency intervention is adopted, thought should be given as to whether the intervention might make the situation worse in the longer run. For example, a drainage sluice with a malfunctioning gate might be closed by dumping a large amount of clay inside. If the subsequent removal of the clay may take a long time, the flood situation on the landside might become worse than it would have been without the emergency measure.

9.2.11 Excessive leakage or flow through a structure

Excessive leakage or flow through a structure may cause, or worsen, flooding on the landside (Figure 9.18). Reasons for such leakage may include:

- Gates not being closed properly due to blockage by a stone.
- Differential settlement/rotation of sections of a concrete wall leading to breakage of seals between the sections and gaps opening up.

Inspiration for emergency measures may be taken from the preceding sections, or Chapters 10 and 11. As this handbook focuses on (earthen) flood embankments, extensive details are not given for the multitude of structures found in practice.

Figure 9.18: Excessive leakage or unwanted flow through a structure

9.2.12 Block sliding or overturning of a structure

Structures like concrete dams, masonry quay walls, retaining walls, abutments, sheet piling or similar, are typically designed considering block sliding or overturning of (large parts of) the structure (Figure 9.19). An important design aspect is the pore pressures underneath the structure which can reduce its the effective weight. To keep these pressures within acceptable limits, appropriate drainage should normally have been included in the design. If extreme conditions arise, proper functioning of this drainage becomes of utmost importance. Issues that may lead to

failure are often linked to limited drainage. Emergency measures should then focus on improving the drainage.

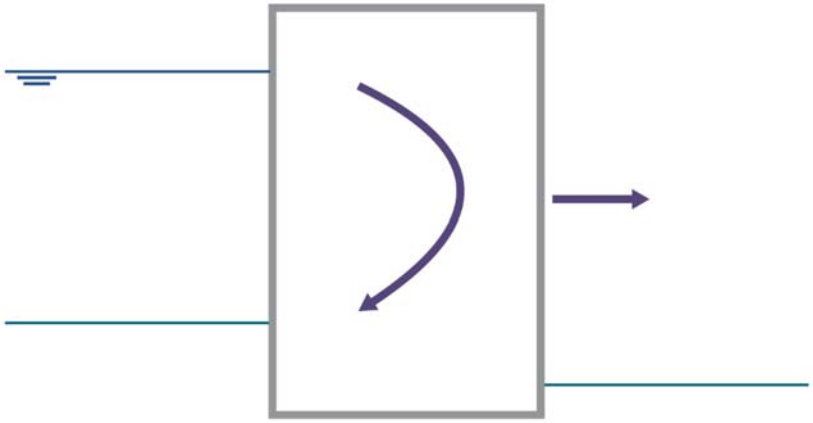

Figure 9.19: Block sliding or overturning of a structure

9.2.13 Structural failure

Structural failure of flood defence structures in general includes other failure mechanisms of gates and movable weirs, and fixed 'hard' defences of concrete, brickwork/blockwork and/or sheet piling. Figure 9.20 shows an example of two failure mechanisms for the steel sheet piles applied at New Orleans. These were originally used to raise the level of flood protection without widening the footprint of a flood embankment (Duncan et al., 2008). Failures observed at New Orleans included overturning of concrete walls due to foundation support in the earth embankment being washed away by overflowing water and/or overtopping waves.

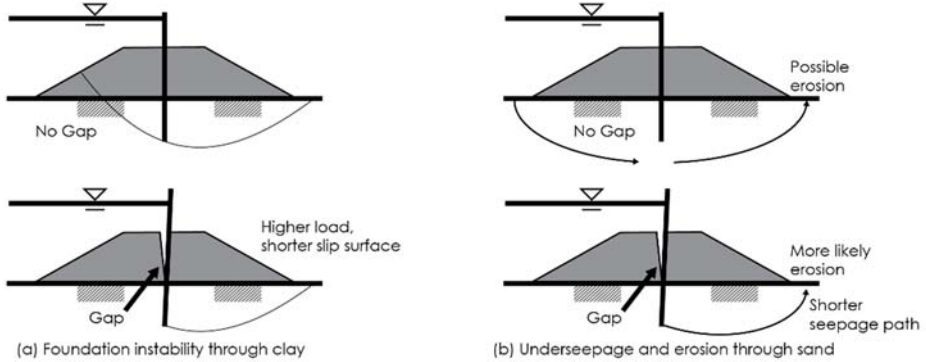

Figure 9.20: Potential I-wall failure mechanisms showing (a) foundation instability through clay and (b) under-seepage and erosion through sand (Duncan et al., 2008)

Structural failure of the body of hard defences is rare. Whilst it is possible that such failure may relate to inadequate design, it is most likely to relate to deterioration of the structure. For example:

- Corrosion of steel sheet piling reducing the bending strength of the piles.
- Chloride-related corrosion of reinforcing steel in reinforced concrete walls with subsequent spalling of the concrete and consequent loss of strength.
- Loss of mortar in the joints of brickwork/blockwork walls reducing their strength.

Other types of structural failure may be less obvious as they do not directly affect the area close to the crest. Examples are the destruction of vegetation like mangrove or willows in the foreshore, and erosion/calving of that foreshore. A related issue is that of failure of a nearby embankment leading to structural failure. Details and specific emergency measures are outside the scope of this handbook.

9.2.14 Flood diversion failures/blockages

Flood diversions (see Section 6.7) are essentially no different from any other water conveying structure, for which the main potential failure mechanisms have been described already above. If such diversions are lost, for example by blockage, the loads on the remaining system will generally increase.

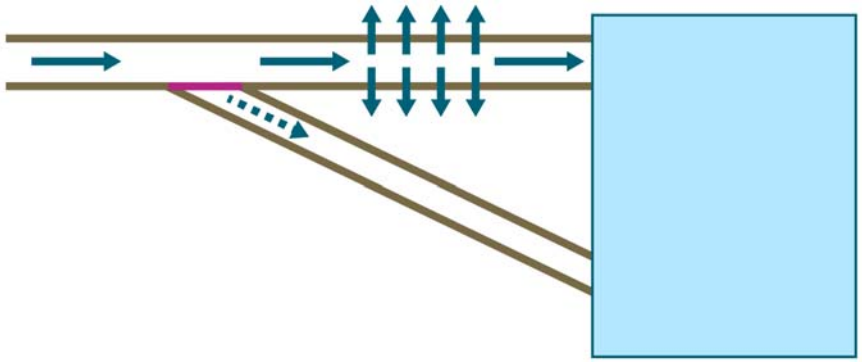

Figure 9.21: Dysfunctional flood diversion causing flooding along the main stream (top view)

A major characteristic of most of these constructions is that they are rarely in use. This creates uncertainty about their intended functionality and generally a higher probability of unexpected behaviour. An example is found at Oroville Dam, CA, where the emergency spillway barely survived when a section of the service spillway failed during its first use in nearly fifty years of operation of the dam (Alvi, 2018; France et al., 2018).

9.3 Fragility curves

A fragility curve expresses the relationship between the flood loading on the flood defence and the conditional probability of failure given that loading. The concept of fragility has been widely used in other industries to characterise structural performance across a range of imposed loads, see Casciati and Faravelli (1991) as cited by Simm and Tarrant (2018).

The fragility curve is simple in concept (Figure 9.22). In classical deterministic design, flood defences are deemed to follow the bold black line and be either not failed (probability of failure = 0) or failed (probability of failure = 1). There is a jump between the two at the nominal failure load. In reality, embankment failure probability follows the red dashed line. For loads in excess of the nominal failure load, the probability of failure may not reach 100% until a load which is rather higher than the nominal failure value. Similarly, at the nominal design load or "standard of protection" there remains a small but finite residual failure probability.

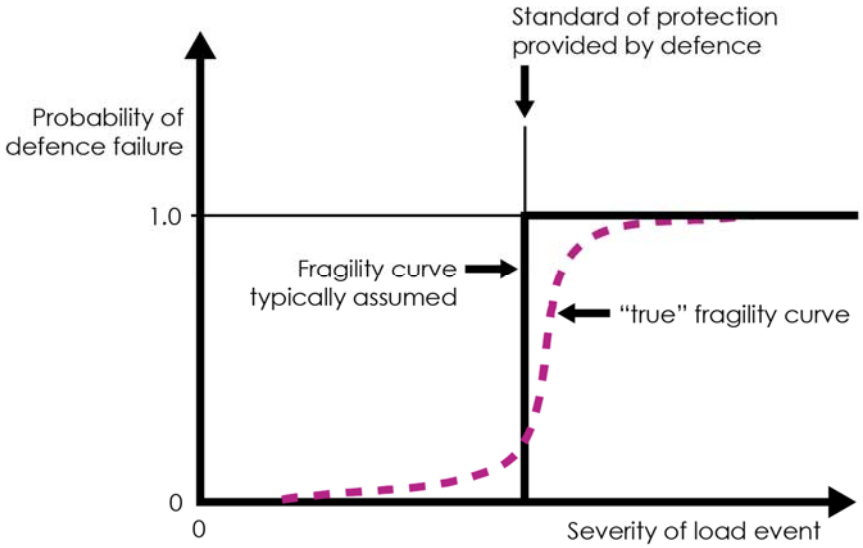

Figure 9.22: True fragility curve compared with deterministic design (presented in Sayers and Meadowcroft, 2005, here taken from Simm et al., 2008)

Fragility curves provide a flexible means to assess the overall safety of a flood defence threatened by various failure mechanisms for a range of conditions. Creating fragility curves for all flood defences in a certain area helps to make clear which defences are the most vulnerable. With limited resources, focusing on the most vulnerable flood defences, as identified by fragility curves, can make the most of available resources. Eventually,

an interactive overview as for example presented in Figure 9.23 may be obtained. This could include forecasts of flood defence sections in various degrees of danger. This will facilitate deployment of people and resources, or even evacuation decisions.

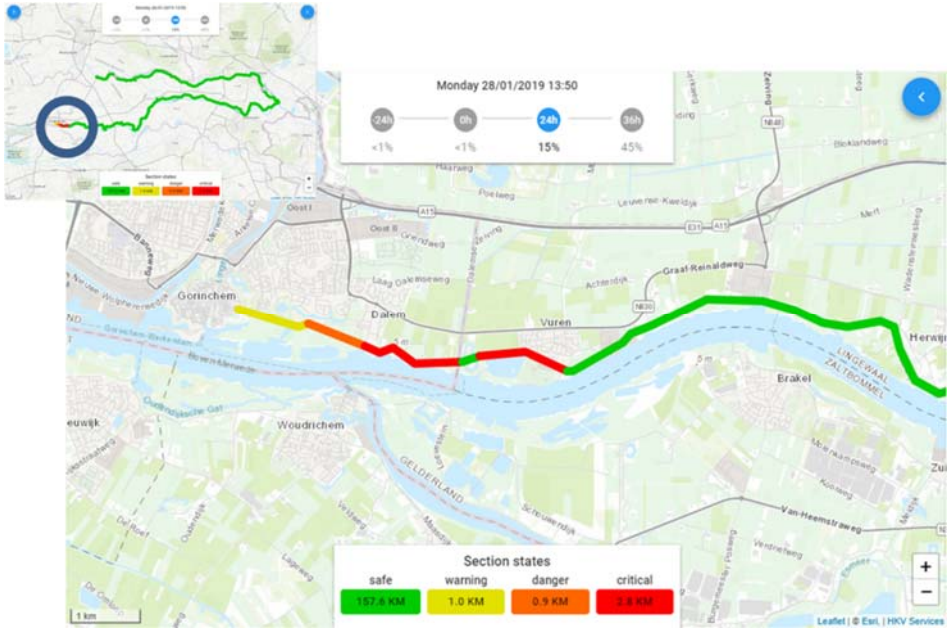

Figure 9.23: Interactive map of an area surrounded by flood defences, including forecasts and alarm levels (Kolen et al., 2019)

Fragility curves can be created based on limited information and then updated as more information is obtained. Examples of additional information might include:

- The defence surviving a known flood level.
- Wave action on the river, causing overtopping of the flood defence while the still water level is still below the crest.
- Results of (additional) soil investigations providing information on the soil profile and strength properties of the various materials and time dependency.
- A flood embankment being strengthened by remedial or improvement works.

The effect of the information and any associated intervention can be made clear in a revision of the fragility curves. The revisions will also make clear which flood defences have become the most vulnerable in the area, i.e. the weakest links may have changed.

There are various ways to generate fragility curves. An overview, discussing advantages and disadvantages, is given by Schultz et al. (2010). Simm et al. (2008) set out a 7-stage process for a deriving a site-specific fragility curve that can be applied even with limited resources. However, Simm et al (2008) also point out that in the event that insufficient information is available to follow the process for developing full fragility curves, it is still possible to identify two points on a fragility curve from deterministic design thinking.

Creation of a simple fragility curve

Consider a flood embankment along a river. The flood embankment was constructed from sandy clay and is 2 m above the general land surface level. Consider the failure mechanisms of overflow induced external erosion, landside slope stability and backward erosion piping:

Because of the limited width of the crown and the steep, highly erodible landside slope, overflow is considered to cause immediate erosion and breaching. Therefore, a water level higher than the crest corresponds to failure (probability = 1).

- Landside slope stability is considered a low likelihood, with the flood embankment being stable at a water level of 1.5 m. For a water level equal to the crest level, a 10% chance of failure is postulated, in this example simply from engineering judgment.
- Backward erosion piping is considered to have a higher likelihood because it is assumed (though not verified) that the clayey blanket layer, with a sand layer underneath, is rather thin. This leads to initial assumptions of 0% of failure at a water level of 1 m, 20% at 1.5 m and 50% at 2 m.

These values are illustrated in the fragility curves in Figure 9.24, together with a combined curve.

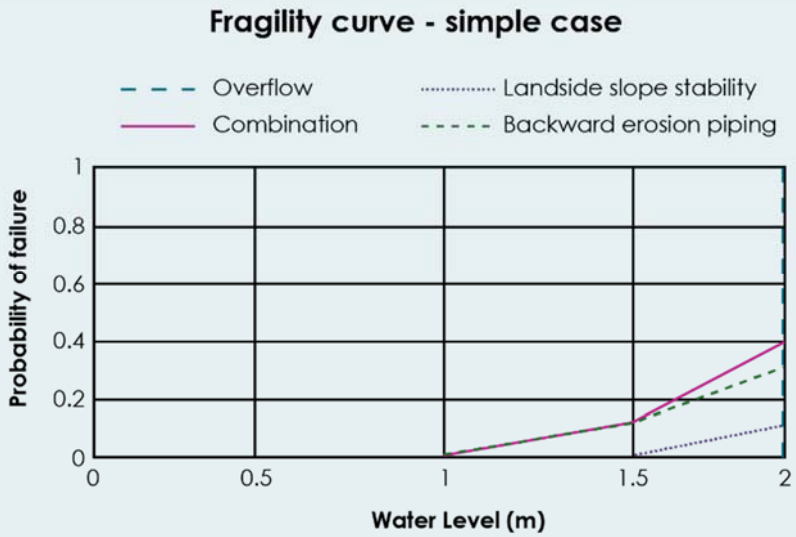

Figure 9.24: Simple example of a fragility curve, initial assumptions

Now consider a flood situation where a water level of 1.6 m did not lead to a flood event. No signs of backward erosion piping (e.g. sand boils) were observed. Yet, some cracks were observed, indicating possible issues with landside slope stability. This leads to some conclusions regarding the fragility of this flood embankment:

- Neglecting time-dependent effects, the flood embankment is considered safe at a water level of 1.6 m.
- It seems likely that the blanket layer has a higher thickness than originally assumed, reducing the vulnerability to backward erosion piping in general.
- The observation of cracks suggests an increase in vulnerability to slope stability.

Using this information, the fragility curve is updated as shown in Figure 9.25.

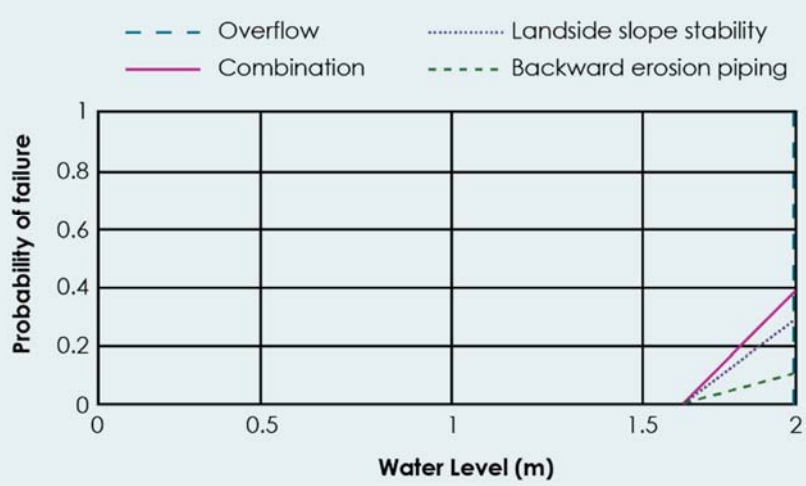

Figure 9.25: Update of the Figure 9.24 after survival of a 1.6 m water level

If flood level higher than 1.6m is anticipated soon, then an emergency measure to improve slope stability may consist of placing additional toe weight. This might consist of sandbags or loose soil placed around the landside toe and on the lower part of the landside slope to reduce the vulnerability to slope instability (see Section 9.2.7).

- At the normal design point (design extreme water level), conventional (conservative) approaches to determine engineering parameters and solutions will typically lead to a probability of failure between 1% and 10%.
- Mean values for engineering parameters (without conservatism bias) may be used to identify hydraulic loading conditions at which the factor of safety against failure is about 1.0. Then for these hydraulic loading conditions the probability of failure will be roughly about 50%.

Although they have significant potential, an extensive use of fragility curves at operational and tactical levels during emergency conditions for flood defences has not yet been identified. In general, fragility curves

provide a versatile approach to prioritization issues that are paramount in emergency response. For further reading, Bachmann et al (2013), Wojciechowska et al. (2015) and Kolen et al. (2019) may serve as suitable starting points.

9.4 Flood embankment breach

A breach occurs when there is a failure in the embankment structure or its foundation, and water breaches through the embankment, causing subsequent erosion down to the base of the embankment and laterally, leaving a large gap in the flood embankment. The breach allows floodwaters to pass through and inundate the area it was intended to protect (see examples in Figures 9.26 and 9.27). Breaches are dangerous because they can lead to rapid and extensive flooding, posing a significant threat to people, property, and the environment.

Breaches can result from any of the mechanisms described in Section 9.2, acting alone or in combination. Mechanisms can include overtopping, surface erosion, general piping, backward erosion piping, structural failure due to animal burrows, or as a follow-up mechanism after an initial failure due to slope instability.

Breach development can occur in different situations:

- High water situations lasting several days up to weeks at river flood embankments.
- Extreme storms lasting one to two days at coastal flood embankment.
- In secondary embankments, although the consequential losses due to inundation are often relatively low and can often be redressed by backwards pumping.

Figure 9.26: An overtopping event in November 2021 caused a 9m long dike breach, Rainbow Slough Levee – Whatcom County, Washington U.S.A. (source: USACE)

Figure 9.27: An overtopping event in November 2021 caused a 61m long dike breach, Timon Road Levee – Whatcom County, Washington U.S.A (source: USACE)

The breaching process for a flood embankment is generally considered to have started once a continuous flow is established across or through the flood embankment. The flow is either through a pipe inside the embankment, growth of the pipe taking place by internal erosion, or via a shallow channel over the embankment, growth of the channel taking place by surface erosion.

In the latter case of surface erosion, all stages of the breaching process are illustrated in Figure 9.28.

1. Initial flow channel creation.
2. Further erosion of the landside slope during a so-called head-cut erosion process: the downstream channel is steepening and widening.
3. Head-cut progression through the crown until the water level on the waterside slope is reached. The widening of the eroded cut continues.
4. Continuation of the erosion of the waterside slope until the waterside toe level is reached.
5. Breach widening and rapid increase of the inflow discharge.
6. Equilibrium breach width when the water levels on both sides become equal.

In practice, the picture is often a more complicated, especially for the early phases. For example, these stages may also occur with only wave overtopping of the crest. Significant erosion of the surface layer, on the crown and/or on the landside slope, will have taken place by then already. Stages 4 and 5 may well also overlap in practice.

Emergency measures to prevent full breach are generally possible up to stage 3. Yet, achieving success becomes increasingly difficult because of the force of the flow and the amount of erosion taking place. Moreover, the operation itself will be highly dangerous to the health and safety of the people involved. Once the stage 4 is reached, successful intervention to stop or close a breach may be considered as practically impossible, especially if:

- There is a significant water head difference between the river/sea and the flooded land behind the defence;
- The soil of the flood embankment or its subsoil has been significantly softened by the presence of water.

From stage 4 onwards, consideration should move to finding ways of closing the breach promptly after the flood has subsided.

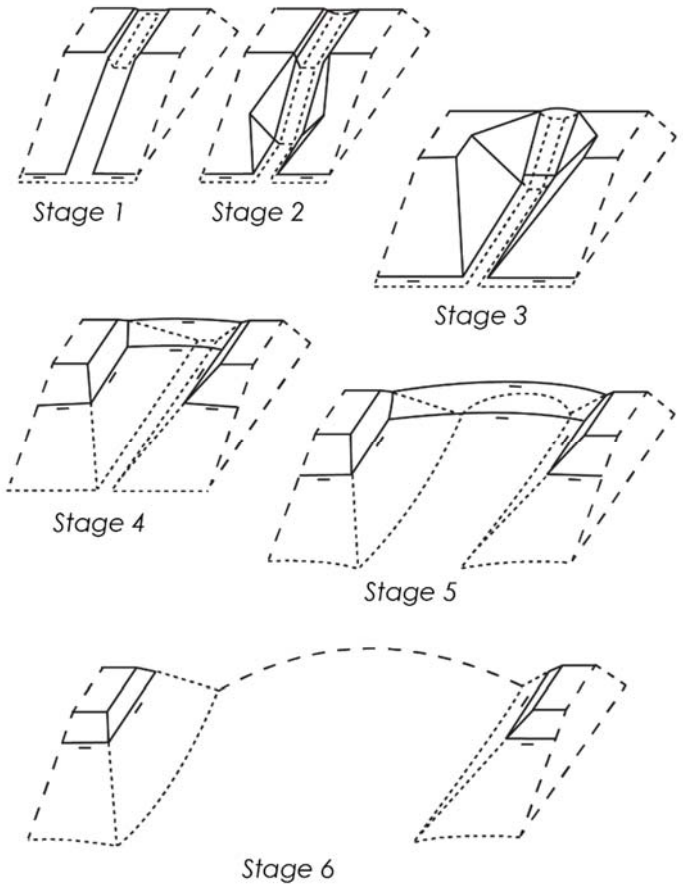

Figure 9.28: Schematic illustration of breach growth in a sandy flood embankment (after Visser, 1998).

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NOTE: This chapter may be cited as: Koelewijn, A., Öttl, M., Pleijter, G. & Havinga, F. (2024) 'Chapter 9: Understanding the problem' In Vonk et al (eds) International Handbook on Emergency Management of Flood Defences. Rijkswaterstaat, Utrecht, and Japan Bosai Platform, Tokyo.

CHAPTER 10

Selecting and designing measures

Key messages:

- **Response should prevent or mitigate failure**
- **Adjust response to time and site constraints**
- **Record response effectiveness for future improvement**

Figure 10.1: Structure of the handbook

Other places to find information on the topics of this chapter

Chapter 3: essentials of preparedness, including resource planning and access to critical materials, equipment, and trained personnel for effective implementation of emergency measures

Chapter 4: essentials of response, including dealing with the practicalities of the response phase to arrive at effective implementation of emergency measures

Chapter 6: overview of flood defence types as well as understanding of possible emergency measures

Chapter 8: guidance on detecting early signs of deterioration through inspections to identify potential failure points quickly

Chapter 9: understanding flood defence failure mechanisms, such as hydraulic pressure effects on stability and erosion, to inform response strategies

Chapter 11: resource allocation and construction techniques, covering materials like sandbags and mobile barriers and construction practices under time constraints

Chapter 12: logistics for efficient resource organization and deployment during high-stress emergency responses

Chapter 13: health, safety and wellbeing guidelines for personnel, supporting the safe design and implementation of emergency measures

Chapter 15: lessons learned from selecting and designing measures

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Note:

The Reader is kindly requested to take note of the Disclaimer on page ii of this handbook.

Chapter title page photograph:

Construction of an emergency barrier (courtesy: USACE)

Key messages:

- **Response should prevent or mitigate failure**. Emergency response measures aim to prevent or mitigate failures in flood defences, involving various interventions such as local impoundments, water system management, and structural enhancements. Responses achieve this by reducing the load on the defence of by raising, strengthening or protecting the defence
- **Adjust response to time and site constraints**. Application of emergency response measures is constrained by logistical capabilities, time pressure, and uncertainties in site conditions.
- **Record response effectiveness for future improvement**. Recording details about the effectiveness of emergency interventions during actual events is essential for advancing and refining their future development.

This chapter provides an overview of emergency response measures in Section 10.1 Subsequent sections then describe five types of emergency response measures:

- Measures to raise the water retaining height of the structure (see section 10.2).
- Measures to reduce the hydraulic load on the water retaining structure (see section 10.3).
- Measures for strengthening the structure to enhance its stability (see section 10.4).
- Measures to protect the flood embankment against surface (external) erosion (see section 10.5).
- Measures to create additional water retaining capacity (other than height) and to substitute an unsafe/unstable flood defence and to deflect floodwater and to act as a barrier to prevent further extension of the flooded area (see section 10.6).

In addition, approaches to the closure of flood embankment breaches are described in Section 10.7.

10.1 Overview of emergency response measures

The aim of applying an effective emergency response measure is to prevent failure of the flood defence from happening or continuing. An emergency measure is a measure that improves the resistance of a flood defence against failure by counteracting overload or applying measures that prevent further deterioration. Unlike regular, well-prepared improvements of flood defences, an emergency measure is typically applied under time pressure. The first signs of deterioration are described in Chapter 8. The causing failure mechanisms are explained in Chapter 9. The techniques available to create the measures are described in Chapter 11. Aspects

concerning logistics and the implementation of these emergency measures are outlined in Chapter 12 and points of special interest concerning health, safety and wellbeing are discussed in Chapter 13.

Emergency response measures concern chiefly:

- Compensating a deficit in water-retaining crest height to prevent overtopping and overflow;
- Adding additional strength to prevent instability, sliding and structural failure;
- Improving the resistance of the revetment to water infiltration and surface erosion, or
- Improving the resistance against internal erosion of an embankment or of the base/foundation of the water defence.

In addition, local load-limiting or load-reducing emergency response measures can be considered. These aim at reducing the head difference between waterside and landside water level, and therefore reducing the resultant force that is affecting the stability of the defence from the waterside. This can be realized by pumping out water from the waterside or creating local impoundments on the landside. Response measures that decrease the effective load acting on the defence (e.g., water system management, management of inland water level by use of pumping-stations, or the use of storm surge barriers, weirs, or flood detention basins) by making use of installations erected beforehand are part of the water management system and hence do not fall in the category of emergency response measures. Emergency response measures in a stricter sense are measures which can be applied to different degrees at different locations without any pre-installed facilities. They are built up at the site of operation depending on the need.

The application of emergency response measures takes place under pressure of time, mostly without a detailed design, using the means available at that time and location and under the given circumstances. For this reason, successful application of emergency response measures depends on good preparedness (see Chapter 3), but also on balancing the availability of resources (i.e. material, equipment, and trained manpower) as discussed in Chapter 11. In the run-up to the execution of the emergency response measure, only a few boundary conditions at the site of operation are known, such as the topography, existing installations and possibly also the soil properties and water permeability. For this reason, it is important to prepare in advance several plans of attack covering different high-water emergency scenarios. The actual response during an emergency must then be devised and adapted at short notice taking account of the measures devised for the various scenarios considered in advance.

Bear in mind that emergency response measures that increase the defence crest level may also increase the load on a flood defence due to their own weight and the higher water level they are retaining.

All emergency measures described in this chapter will require a sufficient time for delivery of materials, equipment and personnel, and the installation of the measure. The available time may be limited, for example in situations such as:

- Pluvial floods, which typically have forecast times of less than one hour.
- Fluvial floods in mountainous regions and straightened river systems, where flash flooding can occur.

According to Masolle *et al* (2018), mobile flood protection systems and often even sandbag replacement systems should be carefully investigated, considering the required preparation and installation timelines. Some mobile systems are not able to cope with the challenges of actual flood events, such as constraints on accessibility and uneven ground conditions.

Inspection Issues discussed in Chapter 8	Issue may indicate numbered failure mechanisms - see subsection(s) 9.2.x
Overflow/overtopping evidence	1, 2, 11
Surface erosion/bare spots	2, 3, 4
Vegetation growth/decline	2, 4, 7, 11, 13
Animal burrows	2, 3, 4, 7
Seepage (soft/wet areas)	3, 4, 11
Sand boils	4
Cracks	4, 5, 6, 7, 8, 12, 13
Bulges or deformations	4, 5, 6, 7, 8, 12, 13
Lowered spots	3, 4, 5, 6, 7, 8, 12, 13
Barrier closure problems	10, 14
Signs of structural failure	13, 14
Blockage of flow channels	14

Subsection 9.2.x	Failure mechanism	Address using emergency measure Section 10.x
1	Overflow and wave overtopping	2, 3
2	Surface erosion	3, 5
3	Internal erosion	3, 4, 5
4	Backward erosion piping	3, 4, 6
5	Liquefaction	6, 7
6	Settlement	2
7	Landside slope instability	3, 4
8	Waterside slope instability	3, 4
9	Failures at transitions	2, 3, 4, 5, 6
10	Untimely gate opening/closing	3, 6, 7
11	Excessive leakage/flow	3, 5, 6
12	Block sliding/overturning	3, 4
13	Structural failure	3, 4
14	Flood diversion failures	3

Subsection 10.x	Emergency measures
2	Raising defence crest
3	Reducing load
4	Strengthening the defence
5	Erosion protection
6	Emergency embankment
7	Breach closure

Figure 10.2: Connections between inspection issues, failure mechanisms and available emergency measures.

The relationships between the various types of emergency measures and the initiating failure mechanisms and associated inspection issues is shown in Figure 10.2, along with cross references between this chapter and Chapters 8 (Assessing and inspecting) and 9 (Understanding the problem).

Protection of other types of structures (e.g. those associated with land or water transport) during flooding and creation of water transport accesses for emergency management and rescue operations are briefly addressed in section 10.8.

10.2 Defence-raising measures

Link with failure mechanisms (Section 9.2):

Section 9.2.1 Overflow/overtopping

Section 9.2.6 Settlement

Rising water levels and wave action can lead to general overtopping of the crest of a flood embankment (see section 9.2.1). Local overtopping can also arise from local depressions in the crest of the flood embankment, either because of local flood embankment settlement or due to animal (cattle or sheep) trampling.

This mechanism, and its consequences, can be prevented or reduced in magnitude by raising the height of the flood embankment with temporary measures. The defence raising would ideally be based on an engineered design which maintains the stability of the flood embankment, for example by broadening the embankment. On the other hand, there is no time to make an engineering design and carry out proper construction works in an emergency. Therefore, the defence raising should include careful monitoring of the effect on the embankment.

The defence raising should create a long continuous raised barrier along the waterside of the crown of the embankment. The raising must accommodate and close off any openings in the flood wall or embankment. Defence raising measures should not be placed in the middle of the crown, otherwise it will no longer be accessible for vehicles and equipment.

To avoid settlements and maintain embankment stability, the weight of the applied emergency defence raising should be limited as far as possible. However, the defence raising should be heavy enough to provide enough frictional forces at its base to resist the horizontal load of the extra waterside water level and waves. Simple sandbag or big bag defence raisings are well-known but do have the disadvantage of their weight. For this reason, many examples of easy-to-construct approaches using lightweight materials have been developed, such as mobile box or tube barriers, hay bales, plastic sheet for additional watertightness, etc.

Examples of various defence raising systems are illustrated in the call out boxes in this section. Some may require the ground to be rather flat for them to be installed. Many commercial, often patented, systems also exist as discussed in Chapter 6 of the International Levee Handbook (CIRIA, 2013).

Soil/gravel crest raising

Crest barriers can be formed with a filling of soil or gravel, in combination with a plastic sheeting seal on top of the fill. Sandbags are placed in rows on top, to hold the sheeting in place. See Figure 10.3

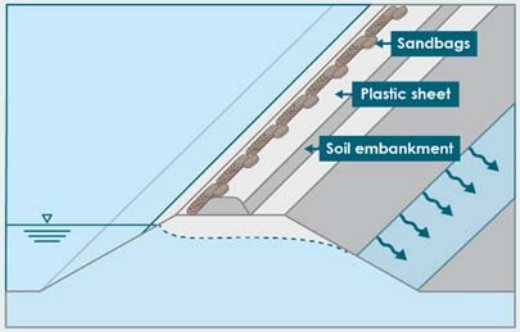


Figure 10.3: Raising the height of the flood embankment on the waterside of the crest with a soil barrier (Source: Guidance for dike defence and dike protection, published by Bavarian State Office of Environment)

Sandbag crest raising

A defence raising with sandbags can be applied up to a height of about a metre as shown in Figures 10.4, 10.5 and 10.6. For a landside slope steeper than 1:2 or a crest width smaller than 3.0 m, additional landside slope stabilisation is recommended.

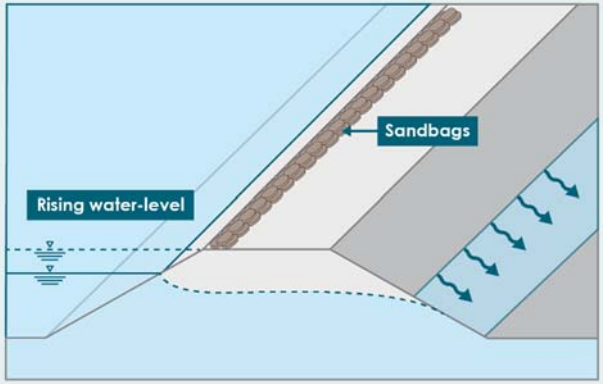


Figure 10.4: Raising the height of the flood embankment on the waterside of the crest with sandbags (Source: Guidance for dike defence and dike protection, published by Bavarian State Office of Environment)

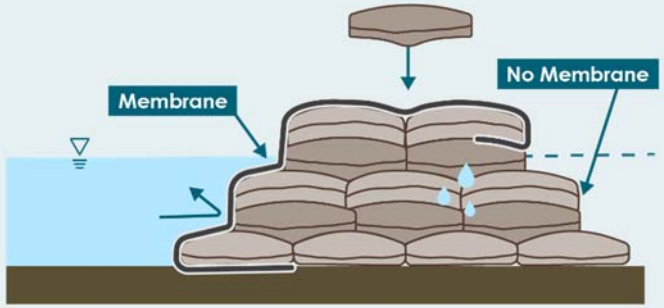


Figure 10.5: Placement of a plastic sheet to improve the watertightness of a sandbag system (Source: Working instruction for sandbags – presentation train the trainer 15-03-2023 by Dutch Working Group Professionalization Dike Inspection)

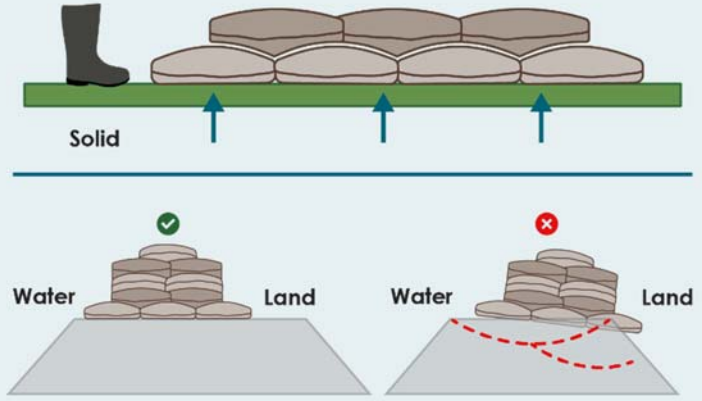


Figure 10.6: Placement of a sandbag system on a smooth base and near to the waterside of the crest (Source: Working instruction for sandbags – presentation train the trainer 15-03-2023 by Dutch Working Group Professionalization Dike Inspection)

Crest raising with sandbags and plastic sheeting (Japanese approach)

This is a technique practiced in Japan that combines sandbags and mobile barriers. The uniqueness of this technique is that it can easily make the mobile barrier function, using only commercially available materials and with little additional loads on the flood embankment. Another advantage is that no technical expertise and heavy equipment are required for placement.

Materials. Filled small sandbags, durable plastic sheeting, steel pins preferably with a ring to tie the rope, hammers to drive the pins into the ground, and rope to tie the plastic sheeting to the pins. See Figure 10.7 (a) and 10.7 (b).

Implementation. First, punch the steel pins into the soil surface at 1m intervals on the waterside of the flood embankment crest. Tie the plastic sheeting to the pins so that it forms an L-shape. Make a small hole in the sheet to tie it to the stake beforehand. When overlapping the sheets to form longer barriers, overlap the upstream sheet 1m over the downstream sheet (see Figure 10.8).

Figure 10.7 (a): Use of sandbags and plastic sheets for raising the defence height (source: Flood Defence Manual published by MLIT Japan)

Figure 10.7(b): Commercially available materials (Source: Flood Defence Manual published by MLIT Japan)

Figure 10.8: Punching the steel and tying the plastic sheet (source: Flood Defence Manual published by MLIT Japan)

Then stretch the plastic sheet in an L-shape, weighting it down with sandbags to prevent the sheet from turning up (see Figure 10.9).

Figure 10.9: Plastic sheet in an L-shape (Source: Flood Defence Manual published by MLIT Japan)

Advantage

- The effect of the plastic sheet on the waterside and under the sandbags ensures that the defence raising is watertight.

Disadvantages

- Attention should be paid to the stability of the measure. For example, it may be moved landward by waves.
- The steel pins must be hammered down into the flood embankment along the waterside of the crest. Where there is a road on the embankment, its subgrade can make this more difficult. Furthermore, the installation of the pins can impair the stability of the slope by inducing crack formation on the crest.

Crest raising using big bags

Big bags can quickly and efficiently add a few additional meters of defence to existing flood defences and structures during events that require it. The advantages of using big bags (quick defence) need to be carefully weighed against disadvantages (weight of the load) to ensure the action does not result in an instability of the levee.

Big bags can also be used to reinforce or elevate roads and pathways that serve as evacuation routes to ensure they remain passable during a flood.

Materials: Big bags, sand, excavator and plastic sheeting.

Advantages: Big bags can be set up very quickly to add additional meters of flood defence. They are cost-effective, space-efficient (easy to package, store, and transport), easy to handle with the right equipment, durable, versatile, environmentally sustainable and weather resistant.

Disadvantages: Big bags add considerable additional weight to the flood defence which may result in instability. Other potential disadvantages may include bulkiness, limited reusability, need for equipment to handle, initial cost considerations, stacking stability.

Examples: (1) At Tukwila, WA, U.S.A. (see Figure 10.10), an existing embankment required few additional running meters of defence for an expected flood event. Big bags were able to be set up quickly and were reinforced with plastic sheeting to further prevent water intrusion.

(2) At Ferndale, WA, U.S.A (see Figure 10.11), big bags were used to add a few additional feet to the existing flood embankment to prevent water from overtopping it. Again, big bags were the most time and cost-effective measure for a temporary problem.

Figure 10.10: Raising the defence of existing embankment at the Green River, Tukwila, WA, U.S.A. (source: U.S. Army Corps of Engineers Operations)

Figure 10.11: Reinforcing Road in Ferndale, WA, U.S.A to protect it from river flooding (source: U.S. Army Corps of Engineers Operations)

Hay bales as a crest-raising method

Hay bales are very light and therefore have almost no effect on the stability of the flood embankment. As a crest-raising method (see Figure 10.12), they are effective against mild wave attack, but less effective at high water levels.

Figure 10.12: Use of hay bales for raising the height of the crest during river flood event 1993 (source: Rijkswaterstaat)

10.3 Hydraulic load-reducing measures

Link with failure mechanisms (Section 9.2):

Section 9.2.1 Overflow/overtopping

Section 9.2.2 Surface erosion

Section 9.2.3 Internal erosion

Section 9.2.4 Backward Erosion Piping (= underneath the flood embankment foundation)

Section 9.2.7 Landside slope instability

Section 9.2.8 Waterside slope instability

Section 9.2.10 Untimely closure / re-opening

Section 9.2.11 Excessive leakage / flow

Section 9.2.12 Block sliding / rotation

Section 9.2.13 Structural failure

Section 9.2.14 Flood diversion failure

10.3.1 River system measures to decrease the hydraulic load

Flood retention reservoirs and floodways (also known as bypasses) can help to lower river water levels. Pumping stations and culverts (conduits) regulate the water level inside the polder and discharge the water of the polder drainage pool and drainage system to the rivers and sea.

Upstream water retention

Most physical emergency response measures are aimed at strengthening existing flood defences to prevent them from failing. An alternative approach is to decrease the hydraulic loads to which a particular stretch of flood defences is exposed. In a fluvial system, one way to do so is to reduce the flood discharge into the endangered area by activating storage in upstream retention basins. However, the retention area and associated structures should have the necessary features (e.g. gate or valve) to allow for diversion of water from the main flow to the hinterland in a controlled manner.

Upstream water diversion

When no diversion infrastructure is in place, flood embankments in the retention area may be breached deliberately to achieve a similar effect.

The traditional method of creating a breach is to use using heavy excavators to excavate a pilot channel through the flood embankment to create an initial breach, which will then widen naturally following the breach process described in Chapter 9. However, deployment of excavators may be impossible or dangerous due to partly flooded access roads and / or saturated flood embankments.

Alternatively, breaches may be initiated using explosives, an approach which has been used on several occasions in the US. Breaching with explosives can have several advantages:

- Flexible and fast deployment: a group of combat engineers can be deployed by boat, over land and even through the air.
- Precise timing of the moment of breach initiation: this could be of importance in relation to the timing of the passing of the discharge peak in a river.

Breaching defences deliberately can be used with confidence in smaller (near) stagnant water systems, such as lakes, basins, and canals; in such locations the effect of the breach is easily predicted based on the surface area of the water body and the size of the retention area.

Breaching flood embankments along rivers can also be effective. For example, for a river discharge of 2400 m^3/s in a deltaic area, a 10 cm water level decrease can be achieved by diverting about 100 m^3/s to a retention area. However, any decision to breach should take account of:

- The timing of the breach creation relative to the passage of the discharge peak down the river.

- The planned/expected eventual size of the breach including the risk of undesirable instability of the flood embankment at adjoining or nearby locations.
- The capacity of the hinterland to absorb the quantity of water that will pass through the breach.

(A separate reason for deliberately breaching a flood embankment may be to release water from an already inundated area. Such breaches are generally downstream of the area that has been inundated.)

Dutch trial for explosively initiating a breach of a flood embankment

The Dutch MoD in 2023 developed and trialled a method (see Figures 10.13 and 10.14) to explosively initiate a flood embankment breach to be used as emergency response measure. The basic concept is that multiple explosive charges are buried inside the flood embankment, using a soil auger to drill the holes. These holes, which will contain prepared explosive charges, are arranged like a string across the flood embankment, starting at the water side up over the crest and onto the landside slope. After detonation, this string of explosions will create an initial ditch, exposing the sandy core and creating a path through which the water will start flowing into the retention area. This water flow will lead to progressive erosion of the initial breach, enlarging it over time, leading to a full-scale breach after a certain time. This method was tested under the following conditions:

- Embankment type: typical Dutch design i.e., erosion resistant clay cover layer (80 cm thickness) on a sandy core. Slopes 1:3, crown width 3m. No road on top, no objects in or on the flood embankment.
- Hydraulic conditions: water level at approximately crest -0.2m.
- Explosives type: standard military grade plastic explosives.

For successful execution the following variables need to be considered:

- Depth of charge (i.e.: the depth at which the explosive charge is placed relative to the flood embankment surface).
- The number of explosive charges required.
- The mass of each explosive per charge.
- The distance between the respective charges.
- The precise location of each charge on the flood embankment.

Figure 10.13: Trial embankment before breaching

Figure 10.14: Flood embankment breach initiation using explosives (source: Dutch Ministry of Defence)

Temporary embankments

In case of pervious underground conditions close to a river, the amount of seepage water (return seepage) rises with the flood water level. An emergency measure that can be used to address this situation is to install an additional containment flood embankment behind the main flood embankment to reduce the load on the main flood embankment as shown in Figure 10.15. If such an embankment is installed in advance of a flood, upward flowing under seepage water will fill the area between the two embankments (see e.g. Figure 10.16). If the water level in the polder exceeds a certain threshold, drainage channels make sure that the seepage water will be drained away from the polder to the hinterland.

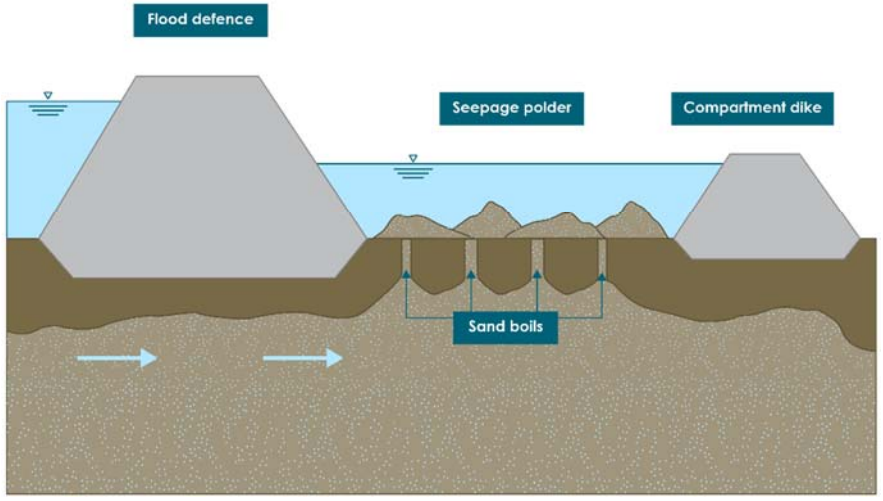


Figure 10.15: Containment flood embankment (right) landward of the main flood embankment (left) to contain seepage water during flooding (courtesy: Landesumweltamt Sachsen-Anhalt, 2002)

Figure 10.16: Containment flood embankment at the Elbe River during flooding in August 2002 (courtesy: Grubert)

Compartment embankments installed as an emergency measure may subsequently be converted to a permanent measure. However, permanent containment embankments need to be properly understood in the event of future emergencies. In other words, a rising water level in the area between the main embankment and the containment embankment is what should occur and requires no emergency intervention; indeed pumping water out of the area will destabilize the flood protection system and worsen the situation.

Flow diversions

Big bags (see Chapter 11) or sheet pile walls can be strategically placed to divert floodwater away from vulnerable areas or redirect it toward designated overflow channels (see example in Figure 10.17).

Figure 10.17: Use of big bags as a cheap method to divert water to allow completion of a permanent project at Stilly Weir, WA, U.S.A. (source: U.S. Army Corps of Engineers Operations)

10.3.2 Locally increasing the landside water level

As explained in Chapter 9, by reducing the hydraulic head difference across a flood defence, the driving forces of internal erosion can be mitigated. This is the case for both general piping (micro-instability, i.e. particle discharge due to seepage flow through a flood embankment core) and for backward erosion piping (BEP).

Measures against micro-instability of the embankment slope

During a flood, water is usually seeping through the core of the flood embankment. If the seepage water reaches the landside slope and drains to the surface (outflow from the flood embankment body), the

stability of the flood embankment can be endangered. This is the case, when the seepage of water additionally erodes and transports material from the body of the flood embankment, resulting in instability of the landside slope. This process of internal erosion can only be stopped when the transport process from inside the flood embankment is ended. This can be done by:

- Reducing the inflow on the water side in the event of concentrated leak erosion, or
- Impoundments on the landside creating a counter water pressure to slow the water flow.

Impoundments are generally created by a temporary ring or cofferdam against the landward slope (see Figures 10.18 to 10.22). Such impoundments may be formed with sandbags, big bags, water filled circular tube systems, or coarse gravel and filter gravel. Impoundments may also be created by creating bulkhead partitions in the drainage ditch behind the flood embankment (see Figure 10.23)

Note that if adopting a landside impoundment, due to the counter pressure the phreatic level inside the flood embankment will locally increase. For this reason, it is important to check that seepage does not commence on adjacent areas of the slope. If seepage does commence, these areas must also be secured by supporting berms.

Water filled circular tube system

An innovative, mobile water-filled tube ring dam, made of reinforced plastic membranes, for seepage water impoundment. Its purpose is to rapidly reduce and confine locally increased seepage flows. First, the membrane will be filled with air using a gasoline-driven booster. After proper placement of the air-filled construction at the landside flood embankment slope or at the flood embankment toe the air fill is replaced by water using a gasoline-driven pump. For filling the ring on site available flood water can be used directly. (source: www.climateinnovationwindow.eu).

Figure 10.18: Mobile water-filled tube ring dam

Sandbag landside impoundment to reduce leakage

The seepage discharge point is bounded to impound the leaking water and build up a counter pressure. Most of the weight of the cofferdam (see Figure 10.19) should be stacked up landward of the flood embankment toe, so that the risk of heave is reduced. The height of the cofferdam should be increased until the flow of seepage water stops. For improved stability, the cofferdam should be built up with a pyramidal cross-section (see details of sandbag construction in Chapter 11).

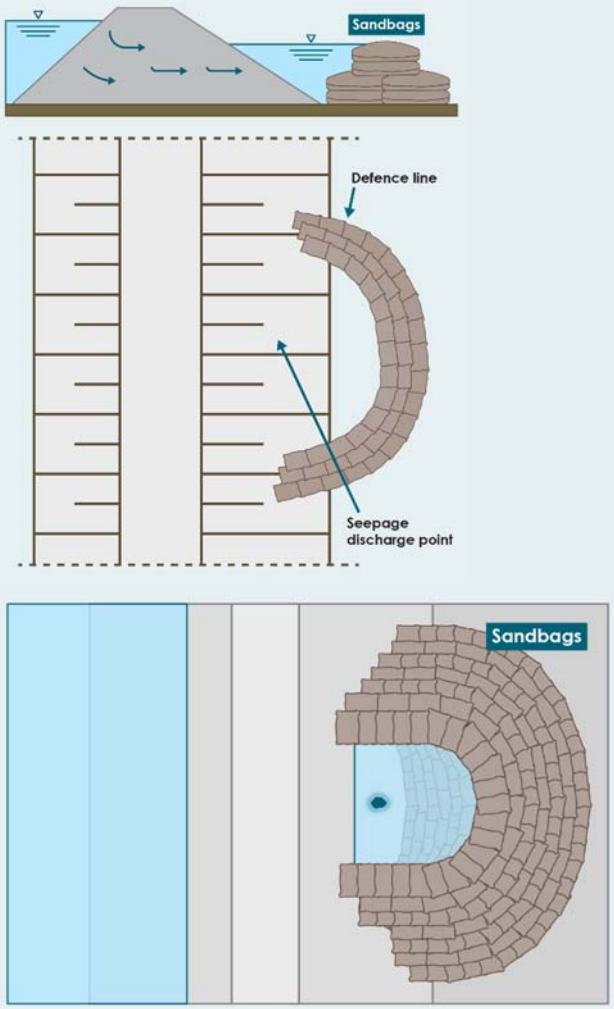


Figure 10.19: Impoundment of seepage water with sandbags (source: Guidance for dike defence and dike protection, published by Bavarian State Office of Environment)

Figure 10.20: Impoundment with sandbags during the Elbe flood disaster in 2006 (courtesy: Robert Jüpner)

Further stabilisation of the landside slope of the flood embankment can be achieved by adding additional weight in a comb-shape as shown in Figure 10.21.

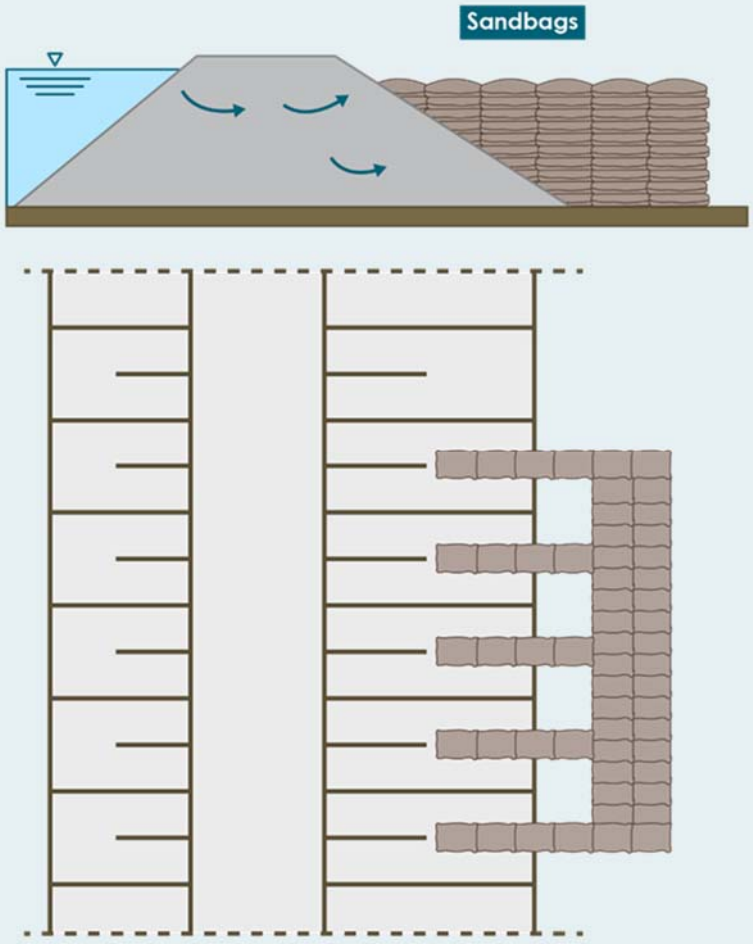


Figure 10.21: Impoundment of leakage with sandbags in a comb-shape (source: adapted from Anleitung für den operativen Hochwasserschutz Teil 2 – Verteidigung von Flussdeichen – Deichsanierung)

Figure 10.22: Impoundment of leakage with sandbags on landside and waterside slope of a flood embankment (courtesy: Robert Jüpner, 2013)

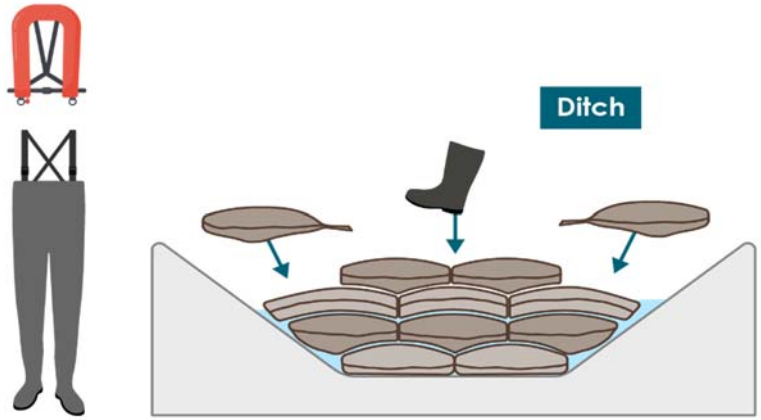


Figure 10.23: Partitioning of a ditch with sandbags to impound landside water levels (source: Working instruction for sandbags – presentation train the trainer 15-03-2023 by Dutch Working Group Professionalization Dike Inspection)

Measures against backward erosion piping at sand boils

If seepage with sand discharge in the form of sand boils appears landside of the flood embankment toe or in the hinterland, the backward erosion piping (BEP) mechanism is occurring (see Section 9.2.4) and must be stopped. Three methods can be considered for use:

1. **Ring shaped cofferdam**. Building up a ring-shaped sandbag construction (Figures 10.24, 10.25 and 10.26) around the sand boil reduces the head difference across the embankment by creating a local impoundment of the seepage water at the landside. The rising water level inside this impoundment counteracts the groundwater flow and will eventually stop the erosion. The height of the impoundment should be limited to the level at which sand transport can be seen to have stopped, although if the river flood levels rise further the impoundment will have to rise further to reflect that. If the water levels within the impoundment increase too much, the additional weight can induce additional cracking of the top layer adjacent to the impoundment, resulting in further sand boils.
   If adopting a landside impoundment, avoid placing a geotextile under the impoundment to impede the washout of the sand particles., This is because it makes it very difficult to see when the sand transport has stopped and thus makes the management of the erosion process difficult.
2. **Gravel filter surcharge.** The discharge of sand can also be stopped by building up a surcharge gravel filter construction (see Figures 10.24 and 10.27). With this method, the discharge of seepage water can still take place, but the transport of fines and thus the backward erosion is prevented.

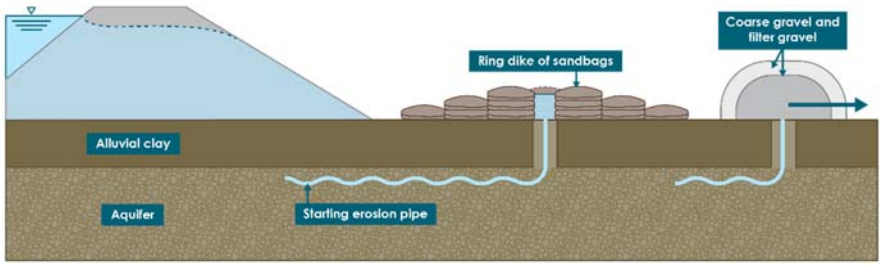


Figure 10.24: Building up an impoundment or a gravel filter in case of backward erosion piping (source: Guidance for dike defence and dike protection, published by Bavarian State Office of Environment)

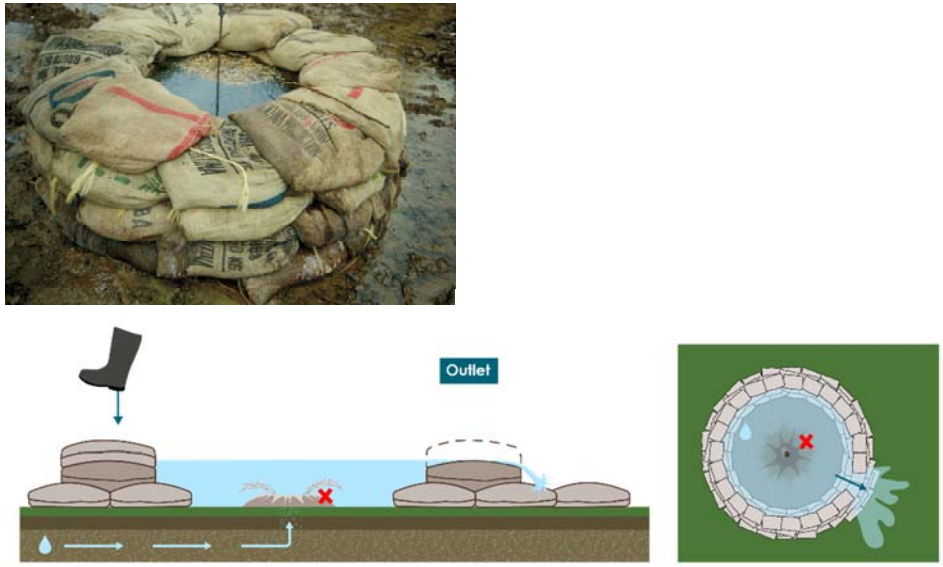


Figure 10.25: Impoundment of a sand boil by a ring flood embankment (source: Working instruction for sandbags – presentation train the trainer 15-03-2023 by Dutch Working Group Professionalization Dike Inspection)

Figure 10.26: Impoundment of sand boiling by using sandbags. The sand boil is covered by a geotextile. Exercise Waterboard Rijn & IJssel 10/20/2022 and flood Limburg 2021 (source: Eric van Kuijk)

Figure 10.27: A covering of filter gravel, covered with ballast gravel at Spijkse Dijk (NL), under everyday circumstances (left) and under high water conditions (right) (source: Ulrich Förster)

3. **Emergency seepage berm**. Such berm has two functions
   a. It increases the seepage path - water must travel a longer distance before reaching the landside.
   b. It adds weight to the levee's base (toe): Helps counteract the water pressure trying to lift the levee (uplift).

A seepage berm is likely to be appropriate when:

a. Numerous sand boils appear across a large area to the landside of the flood embankment.
b. The land behind the levee (landside) is too soft for building a ring levee without causing damage.
c. There's a readily available source of highly permeable, grainy material (like sand or gravel).

Care is needed when creating a seepage berm to:

a. Avoid rapid drops in downstream landside water levels that can trigger new backward erosion piping in that area.
b. Be alert to detect the moment when sand boiling just stops. This will prevent the counter pressure created by the impoundment from getting too high and introducing new seepage and sand boils in the vicinity of the measure. For this reason, it is recommended to let the water flow over the sandbag structure under controlled conditions.

Construction of a seepage berm

Selection of materials for the seepage berm.

The berm should be of permeable material because low permeability berms trap water pressure, forcing it out at the toe of the berm and potentially increasing pressure there. Although the available materials will dictate what is chosen, the berm material should generally be more permeable than the surrounding soil. The less permeable the berm, the wider the berm must be to compensate for the lack of pressure relief.

Good practice for construction of seepage berms

- Start by placing material next to the toe of the flood embankment.
- Build the berm in layers (lifts) moving outward from the levee.
- Do not remove grass or topsoil (sod) beforehand.
- Do not excavate the landside area.

- Use a bulldozer to shape the berm material in lifts of 0.2m to 0.3m.
- The bulldozer should only travel on top of already placed material to avoid damaging the levee or land.

Example images during the construction of an emergency seepage berm are shown in Figure 10.28.

Figure 10.28: Emergency seepage berm established during a flood response event to address seepage across a large field of sandboils on the Missouri River in 2011 (MRLS 471-460) (source: USACE, 2011)

Animal burrows

Animal burrows can be very extensive, resulting in more infiltration of water. As a result, they can reduce the stability of an embankment (see sections 9.2.7 and 9.2.8) and encourage internal erosion (see Section 9.2.3). The entrance of the burrows of most animals can be seen or detected from the outside of the embankment, although the entrance for some mammals (e.g. beaver, muskrat) is generally situated below the (high) water line. Some animals (e.g. beavers, badgers) burrow on both sides of an embankment.

There is no single method for dealing with animal burrows in flood embankments during high water conditions, but the following may be considered:

- Stabilize the landside slope with weighting berms and filter constructions to avoid internal erosion.
- Close off the entrances to animal burrows on the water side slope using string bags (net bags) filled with lumps of bentonite clay that will swell and seal the opening.

10.4 Stability-enhancing measures

Links to failure mechanisms (Section 9.2):

Section 9.2.3 Internal erosion

Section 9.2.4 Backward Erosion Piping (= underneath the flood embankment foundation)

Section 9.2.7 Landside slope instability

Section 9.2.8 Waterside slope instability

Section 9.2.12 Block sliding

Section 9.2.13 Structural failure

10.4.1 Landside slopes of flood embankments

If the crown of the flood embankment is small (< 2.5 m), and the landside slope is very steep, the risk of landside slope instability and subsequent damage due to overflow is high. Due to a high phreatic line (groundwater table) inside the flood embankment the risk of instability is high, which also increases the risk of soil seepage output (internal erosion or general piping as described in 10.6). For very small crests there is a high probability that the whole crest will already slide away as a result of initial sliding such that no residual strength remains.

If instability has not yet occurred, the embankment may be reprofiled to the desired milder slope with gravel or sandbags. However, care

should be taken since there is always a risk that the additional weight may initiate subsequent slope failure.

Gravel fill wedge support for slope stability

Temporary support of the landside slope by applying a wedge-shaped berm of gravel fill (Figure 10.29) is appropriate for larger embankment sections, if sufficient material and equipment for transport and installation is available. The construction of this filling must ensure that seepage water can drain off sufficiently. Therefore, the gravel filter layer should contain little fine-grained material. The construction of the fill must start from the embankment toe (bottom up), to prevent shear failure.

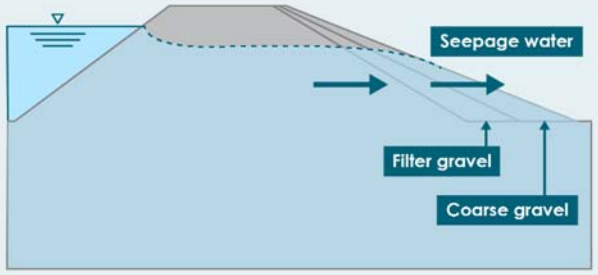


Figure 10.29: Temporary support of the landside slope with filter gravel and coarse gravel (source: Guidance for dike defence and dike protection, published by Bavarian State Office of Environment)

Sandbag wedge support

Because of the large number of sandbags needed, this protection technique is more appropriate for localised applications. To ensure that seepage water can escape, a seepage grid must first be constructed on the slope, starting from the flood embankment toe; the seepage grid can be formed from crossed timbers, shrubs, or specific filter mats. Subsequent, construction of the sandbag load must be built bottom up, also starting at the flood embankment toe. If there is no material available to build up a seepage grid, spaces between the sandbag constructions in the longitudinal direction of the embankment may be used to allow drainage to take place. The images in Figures 10.30 and 10.31 illustrate the approaches.

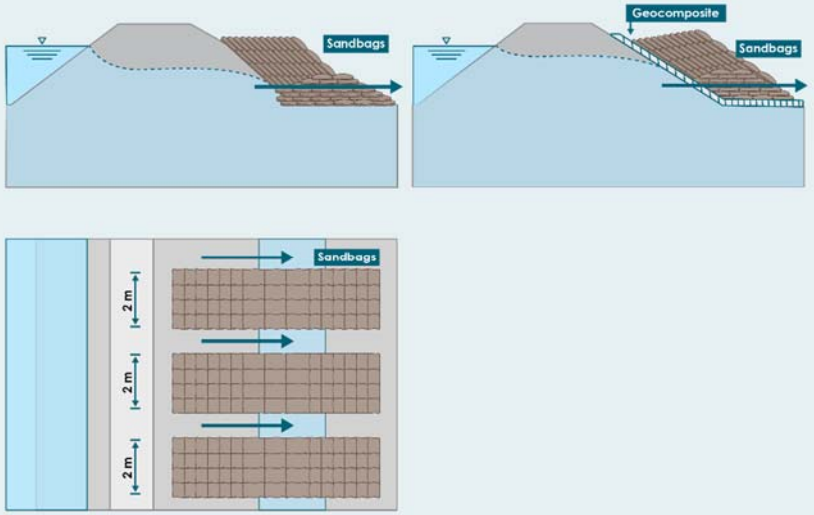


Figure 10.30: Set up of a stability berm with sandbags to counteract against sliding of the slope and a grating enabling seepage water to drain off (source: Guidance for dike defence and dike protection, published by Bavarian State Office of Environment)

Figure 10.31: (a) Stabilizing a landside slope near Woltersum (NL) in 2012 with a sandbag drain on the landside slope. (b) Extra stabilising load is added at the toe of the slope using big bags (courtesy: Wijnand Evers)

If slope instability has already occurred (se e.g. Figure 10.32), a new stable slope will need to be formed using gravel fill and/or sandbags; ideally the resulting slope should be at 1:3 or less. Filling should commence at the toe of the flood embankment, since loading of the slope before the toe has been supported could lead to premature failure or increased seepage.

Figure 10.32: Sliding of landside slope on a flood embankment along the Elbe River, Germany (courtesy: Robert Jüpner)

Gravel reprofiling of unstable slopes

This may be carried out as shown in Figure 10.33(a). Avoid using dynamic compaction when placing the gravel because of its destabilising effect on saturated ground.

Sandbag reprofiling of unstable slopes

This may be carried out as shown in Figure 10.33(b). The sandbags should ideally be laid on a seepage grid (for better drainage of seepage from within the embankment). Note that a waterproof membrane should not laid over the sandbags, since it may cause the phreatic surface to rise, and thus weaken the embankment; a geotextile of sufficient permeability that will not be clogged by fine particles from the embankment may be considered.

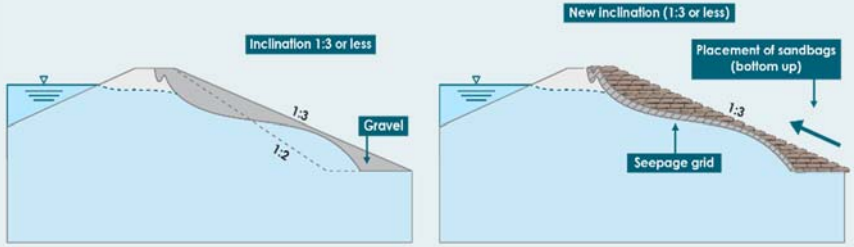


Figure 10.33: Reconstructing the original flood embankment contour using (a) gravel or (b) sandbags (source: Guidance for dike defence and dike protection, published by Bavarian State Office of Environment)

10.4.2 Waterside slopes of flood embankments

If the waterside slope has become unstable locally or over a larger area, the damaged area should be protected against erosion (see also Section 10.5) and be filled up again. This can be achieved (see Figure 10.34) using sandbags, big bags, rock filling and/or fascine mattresses. When larger areas need to be protected, it is important to maintain accessibility to the waterside slope and to avoid damaging or weakening the crown and landside slope.

However, if an immediate water level rise is not expected after the slip has occurred and there is no risk of erosion, a basic recovery using conventional earthworks may be carried out after the flood event. The embankment should have been drained completely before filling up with new material.

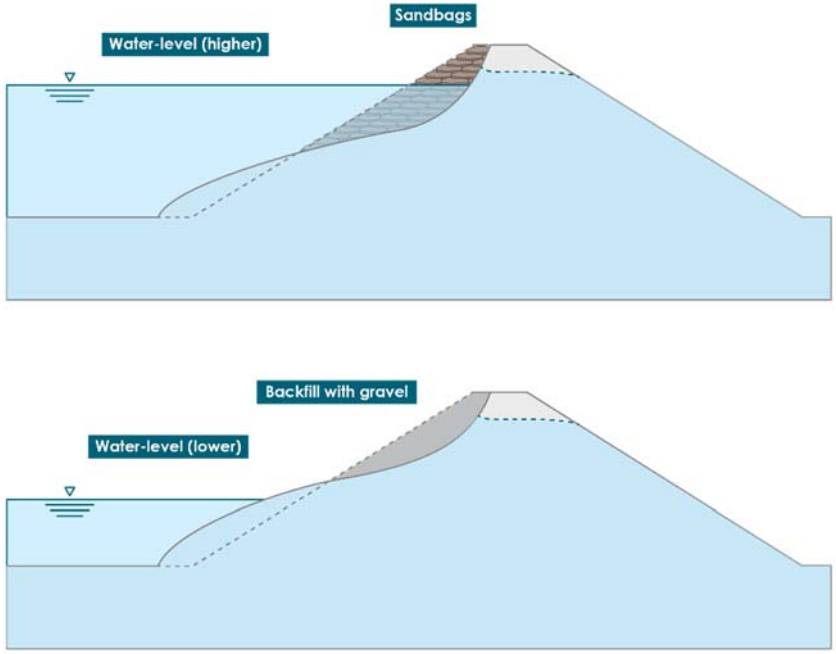


Figure 10.34: Backfilling of a waterside slope slip failure with sandbags or gravel (source: Guidance for dike defence and dike protection, published by Bavarian State Office of Environment)

Reinforcing waterside slope of embankment using big bags

At Island County, WA, U.S.A, the revetment had nearly become a vertical wall due to constant storm and wave action, especially during king tide cycles. As shown in Figure 10.35, big bags were used to provide a temporary approach to stabilise the riprap until a permanent project by the local community could be implemented. This strategy worked in the short-term but by the end of the storm season the big bags were destroyed, and a different approach was needed for the subsequent storm season.

Figure 10.35 : Protecting an existing slope from erosion using big bags (source: U.S. Army Corps of Engineers Operations)

10.5 Protection against surface erosion

Link with failure mechanisms (Section 9.2):

Section 9.2.2 Surface erosion

Section 9.2.3 Internal erosion

Section 9.2.11 Excessive leakage / flow

10.5.1 Protection of the waterside slope

Wave action, floating refuse and debris, sheets of floating ice or longitudinal currents of the river in full spate can damage the waterside surface of a flood embankment, especially if the flood embankment is situated immediately next to the river or sea, i.e., without foreland/floodplain. Initially only a small area of the waterside slope may be damaged but the damaged spot can be enlarged by currents and wave attack. Indeed, the erosion of the surface layer may progress to damage the body of the embankment.

Measures to respond to such damage may include the following:

- Removal of ice and floating refuse to prevent any enlargement of any damage to the revetment and the risk of leakage through the flood embankment. Big bags placed strategically along waterways can prevent floating debris, including fallen trees and debris from damaged structures, from causing damage downstream.
- Installing a covering to protect against surface erosion by wave attack or overtopping, on either a damaged or newly seeded revetment, or even a bare embankment during a construction phase. The landside slope of the embankment should be protected with permeable coverings to allow seepage water to escape. In case of wave overtopping, an impermeable upper membrane should be installed to avoid the overtopping water infiltrating through the covering and causing erosion.
- Repair of superficial, locally restricted damage to the waterside surface of an embankment slope by covering with an appropriate system that matches, or works with, the existing protection (e.g. turf, concrete, asphalt, bricks or riprap). Even simple and temporary protection systems can have a strong effect on reducing the erosive force of the waves or flows at the damaged point.
- Re-sealing of local water entry points through surface clay sealing layers of sand core embankments while the damage is still small. This will prevent higher water tables from arising within the embankments and resulting in higher seepage and potentially eventual embankment breach. (Erosion of the embankment core material and its foundation can also be mitigated by load-reducing measures – see section 10.2).

When selecting the material types and sizes to use to repair the damage, regard should be given to:

- the forces acting (waves, currents in combination with floating refuse).
- the main aim of protection, such as:
  - prevention of initial erosion.
  - prevention of progressive damage of the revetment by further erosion.
  - protection of any clay capping layer against infiltration of water into the embankment.
- the resistance achieved by this cover.

A popular approach for temporary protection of the waterside slope is to use a combination of membranes and sandbags. A locally confined damaged spot can be covered and sealed with a membrane. If there is no need to prevent water ingress into the embankment, the membrane may be a geotextile. However, in the case of sand core embankments, if the flood embankment sealing (clay layer) is already damaged the local defect should be protected against the infiltration of seepage water by using an impermeable plastic membrane. The membrane should be easy to handle but should be strong enough not to tear. Covering longer lengths of embankment will not significantly reduce infiltration.

Protecting waterside slope with membranes and sandbags - Japanese installation method

In Japan, buildability is more important than high erosion protection performance. Erosion on the water side of the flood embankment occurs and responses must be made while the water level is high. Under these circumstances, it is not feasible to use large-scale heavy equipment. Instead, the protection should be assembled in the field using man-sized and commercially available materials. The system involves covering the eroded area with a plastic sheet, using poles and ropes to structure the sheeting and hold it in position, with sandbag weights at the bottom of the slope to prevent the sheeting from being rolled up by the flow. This measure is workable up to 2 m/s flow velocity.

Materials (see Figure 10.36)

- Fine sheeting, easy to handle but should be strong enough not to tear.
- Three types of rope:
  - 1m rope to tie the sheet to the frame poles.
  - 5m rope to tie the weight to the poles.
  - 20m or more rope to hang the sheet on the slope.
- Straight and inexpensive frame poles (bamboo or plastic).
- Sandbags for weighting down the sheeting.

Figure 10.36: Materials for a Japanese erosion protection (source: Flood Defence Manual published by MLIT Japan)

Procedure:

1. Unfold the sheet on a flat ground and make holes in the sheet at the correct intervals; the holes should be small enough to allow the 1m long ropes to pass through.
2. Tie the sheet and frame poles together with the 1m ropes (see Figure 10.37).

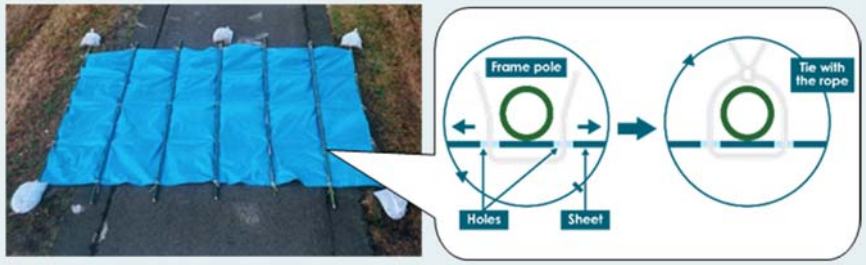


Figure 10.37 Assembling the sheet with the frame poles (source: Flood Defence Manual published by MLIT Japan)

3. Tie the long (20m+) ropes to each frame for anchoring the sheet when hanging upon the waterside slope.

4. Tie the sandbags as weights to the frames to the pole near the bottom of the sheet with the 5m ropes (see Figure 10.38).

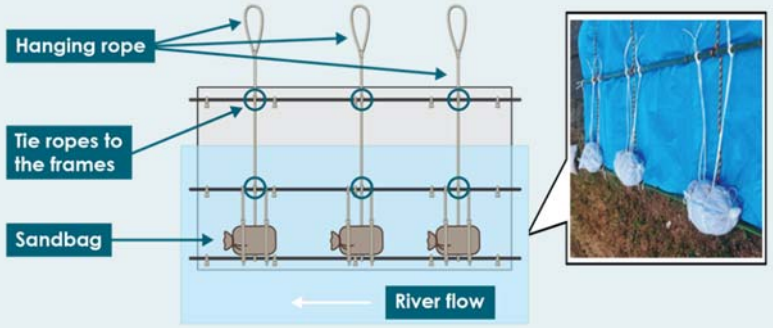


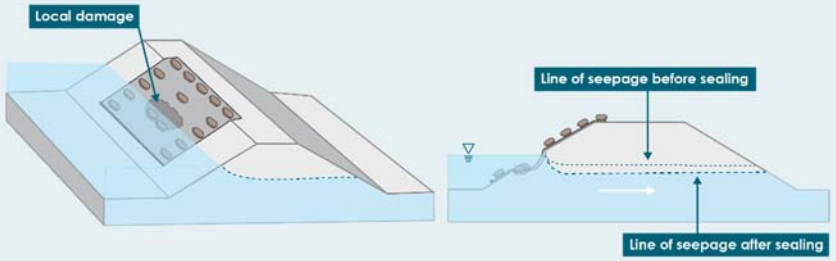
Figure 10.38: Assembling the sheet with the sandbag weights (source: Flood Defence Manual published by MLIT Japan)

5. As it is too dangerous to get into the flooded water and cover the damaged point manually, roll up the assembled sheet, position it above the damaged point, and prepare to hang on the slope. With due care for the safety of workers, unroll the sheet in the river onto the waterside slope (see Figure 10.39).

Figure 10.39: Covering the damaged point with the sheet (source: Flood Defence Manual published by MLIT Japan)

Protecting waterside slope with membranes and sandbags - Dutch and German approach

Method 1. The membrane is fixed onto a steel pipe or iron rod and then rolled up onto it. The free end of the tarpaulin is placed on the flood embankment crest and loaded with sandbags and fixed with pickets. Then the membrane is unwound down the slope and weighted down on both sides with sandbags, including under water (see Figure 10.40). This method is only practical when flow velocities are less than 2 m/s (MLIT, 2021).



(a) (b)

Figure 10.40: Covering of a local damage on the waterside slope to hinder water ingress into the embankment (source: Guidance for dike defence and dike protection, published by Bavarian State Office of Environment)

Method 2. If the water level is still low, the defect can be covered with geotextile or plastic sheets (tarpaulin), fixed by steel clamps (stakes, cramps, or staples) and ropes to lock the sheeting in position. The sheeting can also additionally be fixed by sandbags and poles to prevent the sheeting from being rolled up by the flow or wave action.

Method 3. If the current or wave action is too strong to permit use of a membrane, half-filled sandbags can be dropped into the defect until the original embankment profile is recreated (Figure 10.41). However, when securing the defect, the stability of the slope may be threatened especially if the water level is falling rapidly. For this reason, do not:

- Overload the embankment with too many sandbags.
- Induce dynamic loads like dropping or throwing sandbags onto the slope from a height.

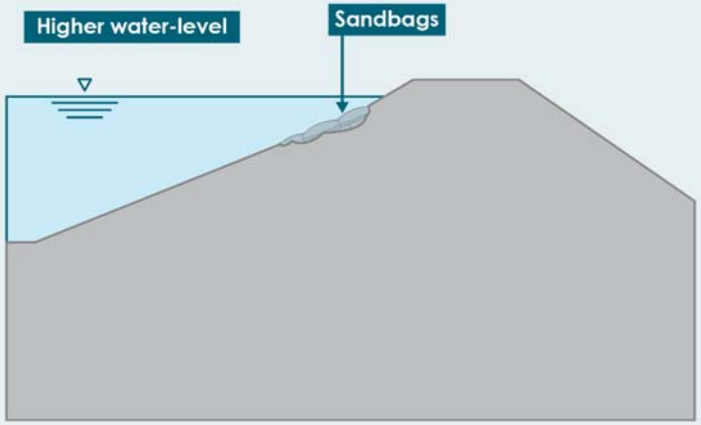


Figure 10.41: Filling up erosion pit at the waterside slope with sandbags (source: Guidance for dike defence and dike protection, published by Bavarian State Office of Environment)

Protecting waterside slopes with fascines and spiles

If water levels are low, erosion pits may be filled with fascines (cylindrical bundle of brushwood or similar material) or branches, fixed by wooden spiles (see Figure 10.42).

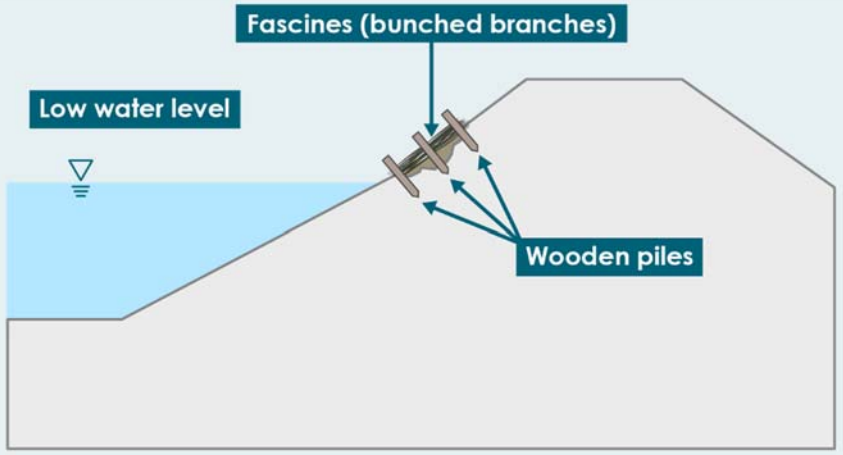


Figure 10.42: Filling erosion pits with fascines and spiles (source: Guidance for dike defence and dike protection, published by Bavarian State Office of Environment)

High velocities during flash floods (e.g. in steep rivers in mountainous areas) may mean that installing membranes to protect flood embankments is not practical. In this situation, trees may be hung on embankment slopes to diminish the impact of the current.

Protecting waterside slopes with trees during flash floods

The installation procedure (see Figure 10.43) is analogous to that for installing membranes:

- Tie weighted sandbags to the trees.
- Hang the trees upside-down in the river down the slope, starting at the downstream side of the defect.
- Anchor the tree trunks with ropes to the landside of the crown of the embankment.

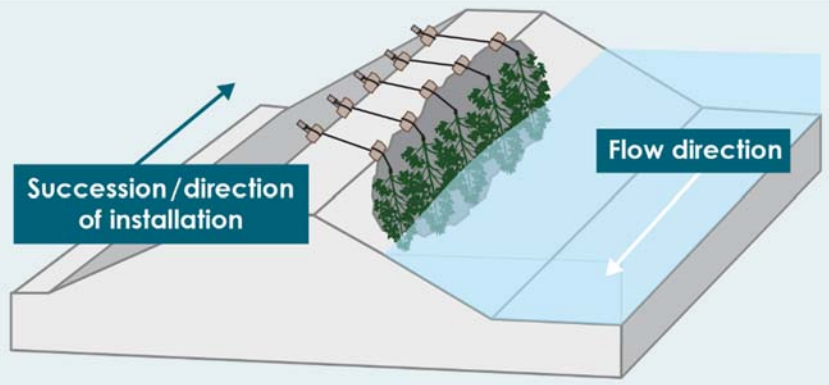


Figure 10.43: Protecting waterside slopes using trees (source: Hinweise zur Deichverteidigung und Deichsicherung published by Bavarian State Office of Environment and Flood Defence Manual published by MLIT Japan)

If the waterside slope has become unstable (see Section 10.4.2), any local slides should always be protected against further erosion as quickly as possible, and any defect backfilled with weighted fascine mattresses, sandbags, or riprap. Local sealing is possible, but if the sliding has occurred over a longer section of the waterside slope, sealing should be avoided. Avoid loading the crest and ensure the accessibility of the waterside slope is maintained without damaging the remaining embankment profile (crown and landside slope).

Guidance on other generic and proprietary erosion protection systems (e.g. armourstone/riprap, paving, asphalt, turf divots, fascines, membranes, sandbags) is widely available (see e.g. CIRIA/CUR/CETMEF, 2007)

Protection of damaged waterside slope against further erosion

At Woltersum in the Netherlands a high water situation in the Wadden Sea made it impossible to drain the canal water to the sea. Due to the rise of the water level in the Canal Eems, the water level was finally higher than the seepage screen (sheet pile wall) in the embankment. This resulted in seepage through the embankment to the landside which threatened the stability of the embankment due to internal erosion. The seepage screen of the embankment was strengthened by placing a sheeting from the crown of the embankment down to the bottom of the canal. The sheeting was also weighted down with sandbags at the bottom of the canal by divers (see Figure 10.44).

At location Deventer in the Netherlands, a ship had been driven off course and rammed a flood embankment. Hereby the armour stone was displaced meters. The damage was repaired with a geotextile that was sunk with steel balls at the right location. Then, the hole was filled up with sandbags up to the water surface (see Figure 10.45).At location x in the Netherlands/Germany, a ship had been driven off course and rammed a flood embankment. Hereby the armour stone was displaced meters. The damage was repaired with a geotextile that was sunk with steel balls at the right location. Then, the hole was filled up with sandbags up to the water surface (see Figures 10.44 and 10.45).

Figure 10.44: Protection and strengthening of the seepage screen on the waterside quay of the Canal Eems nearby Woltersum (The Netherlands) against further erosion (source: Meindert Van)

Figure 10.45: Protection of the waterside slope of an embankment near Deventer against further erosion (courtesy: Wijnand Evers)

Examples of protection against coastal erosion using big bags

Big bags can be used in coastal areas prone to erosion to slow down the erosion process and protect nearby communities. These are only temporary measures designed to buy time until a permanent solution can be implemented. Examples are shown in Figure 10.46 at Barrow, AK, U.S.A and in Figure 10.47 at the island Ameland, The Netherlands.

Figure 10.46: Preventing coastal erosion in Barrow, AK, U.S.A using big bags (source: U.S. Army Corps of Engineers Operations)

Figure 10.47: Preventing coastal erosion at the island Ameland (The Netherlands) using big bags (courtesy: Wijnand Evers)

10.5.2 Protection of the landside slope

When the quality of the permanent landside slope protection (e.g. grass) is insufficient, the landside slope should be protected against surface erosion

- To prevent erosion during overtopping of the embankment that will lead to breach as described in Section 9.4.
- To prevent water infiltration into the core of the flood embankment leading to a water table rise inside the embankment and resulting instability.

The protective measure generally involves covering with some form of temporary sheeting. This covering protects against further surface erosion of the slope and prevents infiltration of overflowing water into the core of the embankment. Installation of sheeting is easy and fast to implement and allows areas of a revetment with several damaged spots can be protected in a single pass.

Installation of sheeting for landward slope protection

Materials required:

- Plastic sheeting or geotextile to cover weak spots.
- Pegs or other fixings for the sheeting (see Figure 10.48).
- Fat clay (if required for prefilling of damage to clay cover).
- Sandbags.

Figure 10.48: Types of different fixing material such as pegs, staples, and pins (courtesy: Ulrich Förster)

Installation procedure.

- Repair any damage to the embankment clay cover using using fat (i.e. expansive) clay.
- Fix the sheeting on the crest of the embankment with pins at intervals of 0.5 m.
- Roll the sheeting down the slope to cover it and fix the sheeting again with pins driven into the grass cover of the embankment. Space the pins at intervals down the slope of not more than 1m. In the horizontal direction, install the pins every 2 m.
- When overlap of additional sheets is necessary down the slope, place the lower sheet under the upper sheet in a roof tile manner, such that overflowing water can run off easily.
- When overlap of additional sheets is required in the horizontal direction, take account of the direction of the wind and the current to prevent sheets folding back and coming loose at the fixings (see Figure 10.49).

- It is difficult to work in strong winds. Coverings are easier to handle if you let the wind blow into the roll and fix the sheeting right behind the roll.
- Use the sandbags to divert flow around any weak spot.

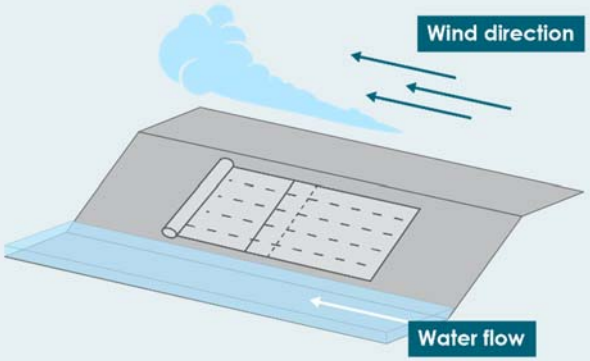


Figure 10.49: Installation of horizontal sheeting overlaps.

Selection of the fabric depends on the requirements for strength and permeability. Fabrics include:

- Geotextiles (woven or non-woven) which should always be permeable to a degree.
- Biodegradable natural cloths made from jute, coco, hemp whose permeability varies considerably.
- Impermeable light tarpaulins or heavier EPDM (ethylene propylene diene monomer) rubber sheets.

The material used affects the infiltration resistance of the covering and the maintenance of the vegetation that is covered by it.

Impermeable fabrics can hinder ingress of water to core of the flood embankment and therefore limit the rise of the water table inside the embankment.

Biodegradable coverings do not have to be removed after the flood, although whether they are left will depend on the overall maintenance strategy.

Permeable fabrics (permeable for water, air, and light) have less impact on the development of the vegetation that is covered, but the water penetration through the sheeting can cause further erosion of weak spots. If a permeable fabric is used for the protection of clay capped sand core embankments, any damage to the clay cover must first be filled in with fat (i.e. expansive) clay.

Tests on the use of permeable fabrics for landside slope protection

Tests were conducted in the Netherlands on landside face protection systems using an overtopping simulator (Figure 10.50). Covering of the landside slope only with a permeable geotextile had limited erosion inhibiting effect during overtopping when:

- There was a damage to the grass cover and underlying clay layer, and
- The edges of the geotextile were not fastened securely to the face of the embankment.

Better performance was achieved during testing when any existing damage was repaired with fat (expansive) clay before covering (source: Ulrich Förster).

Figure 10.50: (Left) Overtopping test on a geotextile covered landside slope. (Right) surface damage repaired with fat clay before covering and testing (courtesy: Ulrich Förster)

10.6 Construction of an additional emergency embankment

Link with failure mechanisms (Section 9.2):

Section 9.2.4 Backward Erosion Piping

Section 9.2.5 Liquefaction

Section 9.2.10 Untimely closure / re-opening

Section 9.2.11 Excessive leakage / flow

10.6.1 Semicircular emergency embankment

A semicircular emergency embankment can be constructed around the defect on the landside of the flood embankment (see Figure 10.51) under the following conditions:

- The damaged part of the embankment cannot be addressed directly.
- Overflow at a local depression or weakening of the flood embankment crest is imminent.
- There is adequate time to construct the emergency embankment. (The construction of a semicircular emergency embankment over a considerable distance will take some time, needs a lot of material and requires a high input of workforce and equipment.)

The new embankment must be joined to the existing defence at embankment segments that still have sufficient stability.

An emergency embankment is generally built up with homogeneous fill material or sandbags. The use of plastic sheeting on the water side slope is a practical way of providing water-tightness.

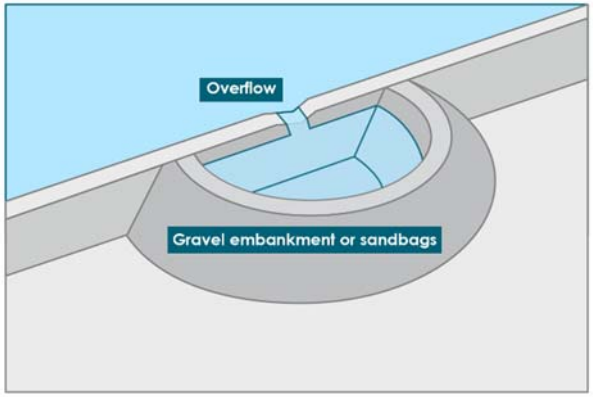


Figure 10.51: Principle of an emergency embankment, surrounding the weak part of the flood defence (adapted from: Guidance for dike defence and dike protection, published by Bavarian State Office of Environment)

10.6.2 Temporary defences

If an area is at risk of flooding, floodwaters can be prevented from entering critical areas using temporary flood defences (see Section 6.4), including sandbags or big bags filled with sand or soil. These can be located along riverbanks, shorelines, or around buildings.

Use of big bags as temporary flood defences

Big bags can be arranged to form temporary flood walls, providing protection to homes, businesses, and infrastructure such as electrical substations and water treatment plants. The benefits of using big bags for temporary flood walls is their ease of deployment and their relatively low costs.

At Ferndale, WA, U.S.A, big bags were used as a temporary measure to protect the road and infrastructure (see Figure 10.52). In addition to big bags, plastic sheeting was wrapped around to reduce water seepage. In this case, this was the most cost-effective and timely measure to provide the temporary level of protection required.

Figure 10.52: Protecting a building from flooding in Ferndale, WA, U.S.A (source: U.S. Army Corps of Engineers Operations)

At Kitsap County, WA, U.S.A. , big bags were used to protect the community in Kitsap County from an expected king tide (see Figure 10.53). In this instance, the big bags again presented as the most cost-effective and timely measure. Because the site had enough space for heavy machinery needed to fill the larger sacks, they were the preferred method over traditional sandbags.

Figure 10.53: Big bags used to protect homes in Kitsap County, WA, U.S.A. during a king tide event (source: U.S. Army Corps of Engineers Operations)

10.7 Embankment breach closure

As explained in Section 9.4, initiation of failure of flood embankments by various mechanisms (external erosion, internal erosion and mass instability) may eventually progress to a complete breach. Flood embankment breaches can have severe consequences and are a

major concern in areas susceptible to flooding, particularly during heavy rain, storm surges, or other extreme weather events.

Efforts can be made to prevent and mitigate flood embankment breaches through proper construction, regular maintenance, and emergency response plans. When a flood embankment breach occurs, it often necessitates immediate and coordinated efforts to repair the breach (ideally before it becomes too large) and mitigate the flooding impacts. The coordinated response that typically involves several key steps and efforts by local authorities, emergency management agencies, and other relevant organizations.

The specific actions taken may vary depending on the severity of the breach and the local resources available. The actions by which flood embankment breaches should be addressed include the following steps:

1. **Emergency alert and evacuation:** When the breach of a flood embankment occurs or is imminent, authorities issue emergency alerts to notify the public of the danger. Evacuation orders may be issued to ensure the safety of residents in the affected areas.
2. **Response coordination:** Emergency management agencies coordinate their efforts to respond to the flood embankment breach. This may involve setting up Emergency Operations Centres to manage the response.
3. **Reinforcement or repair of the flood embankment:** The immediate priority is to stop the flow of water and prevent the breach from growing beyond stage 3 (see Section 9.4). Repair crews are dispatched to the breach site to begin work on patching or reinforcement, using the methods discussed in previous sections.
4. **Floodwater management:** Efforts are made to manage and control the floodwaters that have entered the affected area. Pumps and other flood-fighting equipment may be deployed to remove excess water.
5. **Search and rescue:** Emergency responders conduct search and rescue operations to assist people who may be stranded or in immediate danger due to the breach.
6. **Continued monitoring and intervention:** If the breach could not be prevented, its growth is monitored and options to effect a closure evaluated and if possible implemented. If it has been possible to repair the initial breach, authorities still continue to monitor the situation to ensure the stability of the embankment and to respond to any further developments or secondary breaches.
7. **Public information:** Regular updates and communication with the public are crucial to provide information on the situation, safety instructions, and evacuation orders.
8. **Recovery efforts:** Once the immediate crisis is under control, recovery efforts begin, which can include assessing damage, aiding affected individuals and communities, and facilitating closure of any breach that could not be prevented, including long-term repairs and improvements to the flood defence system.

The response to a flood embankment breach can vary depending on the local context, available resources, and the size and severity of the breach. In some cases, it may be necessary to bring in specialized engineering expertise to assess the situation and plan long-term repairs and improvements to the flood embankment system to prevent future breaches. The goal is to protect lives, property, and the environment while addressing the immediate and long-term consequences of the breach.

10.7.1 Strategies and aspects concerning breach closure

The breaching mechanism in combination with water depth rate of discharge determine whether it is possible to achieve a successful breach closure. Every breach of a flood embankment is different and therefore no patent remedy or “cookbook” for breach closures exists. It is important to identify the breach initiating failure mechanism,

because this can decisively affect the strategy adopted to attempt to close the breach.

In general terms, as explained in Section 9.4, the best option is to protect the breach from progressing beyond the early stages. If only the flood embankment crest is lost, due to a short period of overflow or when an animal burrow is directing flow from the landside to the waterside slope near the crest, progression can be inhibited by an immediate closure of the breach with sandbags.

Attempts to close a breach at a slightly later stage to limit the inundation of the hinterland, and damage remain reasonable. Empirically, breaches of 1 to 2 m width can be successfully closed. Breaches of more than 5 m width are very difficult to close.

However, closing a breach which is rapidly enlarging is much more difficult, the difference in hydraulic head on both sides of the flood embankment leading to strong currents and erosion through the breach. At that later stage, any filling material is likely to be washed away by the strong flow of water. The resulting breaches may exceed 100m in length, sometimes reaching 400m as illustrated by the following:

- Breach of 164 m length at the Hutouo River South Levee in August (1996).
- Breach of 390 m at Li Polder, part of the flood storage polder Lizhou Polder in the drainage basis of the Yangtze River (1998).

Breach closure problems at Fischbeck, Germany, June 16, 2013

The flood embankment breach at Fischbeck, Germany, in 2013 turned out to be very difficult to close as shown in Figure 10.54. Closure was attempted during the 4th and 5th stages of breaching (see Section 9.4) and there were several failed attempts. The eventual closure of the breach by sinking several cargo ships into the gap turned out to be very complex and laborious and succeeded only when the water levels on both sides of the breach had equalised.

Figure 10.54: Failure of breach closure at Fischbeck, June 16, 2013 (Gorges et al., 2018)

Therefore, breaching must be prevented as early and as long as possible to

- Restrict physical and economic damage, injuries and fatalities.
- To allow any evacuation required to be accomplished.

Once the hinterland has been flooded and the rate of flow through the breach has reduced, closure of the breach may be attempted, or attempted again. For some large flood embankment breaches, e.g., 2013 at the Elbe River, unusual closing procedures have been successfully carried out and documented (LHW, 2013).

Planning the closure of an embankment breach should take focus on the following:

- Use of previously developed breach scenarios and associated responses, which take account of the short lead time and the limited logistical support (manpower, material and means of transport) that will be available.
- Inspections (see chapter 8) and readiness and rapid response to close any breach immediately at the first signs of threat of breaching. This included monitoring the quality and integrity of the resultant closure works (e.g. using divers if conditions make this possible safely).
- It is often not possible to mend a breach completely during an emergency repair action. Therefore, the measures must be aimed at preventing further erosion of the flood embankment material.

If a repair of a breach is to be attempted, take the following into account:

- Try to close the breach as rapidly as possible (do not wait for the current to diminish) because of the fast vertical and lateral enlargement of the breach.
- Work simultaneously on both edges of the breach to protect the breach from broadening. Otherwise, the current between the edge of the breach and the filling will lead to stronger erosion of the non-protected edge.
- For safe working and placement of materials in the correct position, consider using the following:
  - Helicopters;
  - Operating machinery from pontoons on the water side of the breach rather than from the flood embankment crown to avoid overloading. (However, this is time consuming and, for safety reasons, is only possible in non-flowing water.
- Where possible, start by using materials that can trap subsequent fill materials like big bags or rocks or prevent them from being flushed away so easily. For example,
  - Long framework-like structures (e.g. electricity pylons, steel mesh or stone wire mesh gabions, 'hedgehog' tank traps) fixed along stronger parts of the waterside of the embankment to bridge the breach gap.
  - Fascine mattresses to trap or contain rock materials. (However, these are heavy and stiff and therefore not easy to place in broader and deeper breaches).
  - If feasible, a row of driven piles.
- As well as placing materials to close the breach directly, consider deflecting currents by constructing an angled embankment on the upstream side of the breach.

If part of the existing embankment has already been lost, any emergency embankment (see Section 10.6) should be constructed starting and ending further away from the defect. If river or seabed material has been lost in the area of the breach (e.g. due to liquefaction of the foreland), there will be a need to build up the emergency embankment layer by layer from the bottom to the top. The line of the new embankment should be kept away from unstable material in the eroded/slumped area in order to be secure against subsequent failures/losses.

Factors that may make preventing or closing a breach difficult or impossible include:

- Water flows at a higher velocity along and underneath any filler element dropped inside a breach. Through this, more erosion occurs, leading to deepening and widening of the breach.
- Excessive precipitation and long-lasting high-water causes softening of the embankment material and limits the accessibility and driveability of the flood embankment for vehicles for inspections and emergency measures.
- Dangers to the health and safety of personnel working in the immediate vicinity of the breach (see also Chapter 13), given

both the adverse weather conditions and the reduced reliability of the embankment at high water, especially considering:

- The weakened and irregular edges of the breach due to the saturation of embankment material because of the high water, rainfall and any wave action.
- The possibility of vibrations initiated by dropping heavy materials (e.g. big bags) from a great height, resulting in liquefaction or flow slides.

Breach closure near Nieuwerkerk aan den IJssel, The Netherlands, 1953

A rare example of a successful breach closure at the latest possible stage (stage 3, developing already towards stage 4) was during the famous 1953 storm surge which devastated parts of the Netherlands and England. The eventual closure is shown in Figure 10.55

Figure 10.55: Small vessel used to block a breach near Nieuwerkerk aan den IJssel on February 1, 1953 (Picture from https://historiek.net/arie-evegroen-watersnood-1953-zuid-holland/80774/).

Note that if breaches occur in intermediate or secondary flood embankments (e.g. internal defences around a polder area), alternative options may be considered that would not be available for primary defences. The most obvious measure is the compartmentalization of the water body and to reduce the flow rate. The consequential loss of water by inundation of a polder via a breach for such an embankment is relatively low and pumping-stations often have sufficient capacity to return that amount of water.

10.8 Protection of other structures

Infrastructural elements with a flood defence function, such as lock, sluices, and weirs, but also dry infrastructure embankments (such as road, railroad embankments and tunnels) can be prone to failure and need to be protected or secured if damaged during a flood event.

Big bags can prove a useful tool in such situations, for example:

Protection of Bridge Abutments and other structures: Big bags can be placed around such structures (see e.g. Figure 10.56) to protect them from scour and erosion caused by fast-flowing floodwaters.

Temporary Boat Ramps: Big bags can be stacked to create makeshift boat ramps for rescue and transportation purposes in flooded areas.

Counterbalance: Big bags can be used to stabilize objects or structures threatened by the force of floodwaters. This can be particularly useful when dealing with the threat of buoyant objects or structures being dislodged or overturned by rising water.

Figure 10.56: Protection of construction site discharge sluice in the Afsluitdijk near Den Oever (source: RWS, W.F. Louwersheimer)

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CHAPTER 11

Techniques for emergency measures

Key messages:

- **Techniques are constrained by time and logistics**
- **Follow best practices, even for simple techniques**

Figure 11.1: Structure of the handbook

Other places to find information on the topics of this chapter

Chapter 3: Essentials for preparedness to ensure that emergency interventions are both feasible and effective

Chapter 4: Essentials of response, including dealing with the practicalities of the response phase to arrive at effective implementation of emergency measures

Chapter 6: Overview of flood defence types as well as understanding of possible emergency measures

Chapter 8: Assessment and inspection procedures to identify risks and guide the choice of techniques for emergency response

Chapter 9: Overview of failure mechanisms to consider when planning and implementing emergency measures

Chapter 10: Flood control techniques, including sandbags and big bags, for water control and reinforcement

Chapter 12: Steps for securing materials and equipment essential for applying emergency measures effectively

Chapter 13: Considerations for health, safety and wellbeing

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Note:

The Reader is kindly requested to take note of the Disclaimer on page ii of this handbook.

Chapter title page photograph:

On-site kick-off meeting to arrive at an emergency embankment using sandbags at Flood Proof Holland testing facility (courtesy: Eric Huijskes)

Key messages

- **Techniques are constrained by time and logistics**. Techniques for emergency response measures are restricted to those which can be implemented under the constraints of logistical capabilities, time pressure, and uncertainties in site conditions.
- **Follow best practices, even for simple techniques**. All techniques, even if apparently simple, still have a number of practical best practices which should be followed to ensure their maximum effectiveness and to avoid negative consequences.

This chapter discusses the details of some of the techniques that can be called upon when considering measures (see Chapter 10) to deal with potential failure mechanisms (see Chapter 9) that may arise during an emergency. The selection of techniques should be based on:

- The measure(s) that have been selected.
- The availability of materials staff and equipment to implement the technique.

Many different materials and application-(in)dependent products can be used when implementing an emergency response measure. These materials and products have different functionalities and merits, but also have advantages and disadvantages related to the field of application and rapidity of implementation. To avoid faults and failures, where possible a proven type of material should be adopted rather than untried measures; but in the end, the choice of material and system is part of the risk-based decision-making process.

This chapter describes the important features of some of the most commonly used materials and systems, including from the following:

- Sandbag systems (sandbags, big bags) – see Sections 10.1 and 10.2.
- Sandbag replacement systems (like flexible bulk containers or other mobile location-independent temporary systems) – see Section 10.3.
- Strong waterproof fabrics including EPDM (hard-wearing ethylene propylene-diene monomer rubbers).
- Geotextile as covers in combination with bracings and anchors.
- Bulk material (such as riprap, gravel, sand, armourstone).
- Fascines (mattresses and revetment), planks, boards, beams, rods, staples and wood pickets.
- Mobile pumping systems – see Section 10.5.

The use and placing of bulk fill materials should follow good practice as summarised elsewhere, including:

- For earthworks - Chapter 10 of the International Levee Handbook (CIRIA, 2013).
- For riprap and armourstone – the Rock Manual (CIRIA/CUR/CETMEF, 2007).

The suitability of these various techniques for the measures set out in Chapter 10 are summarised in Figure 11.2.

No system should be adopted without the appropriate planning (whenever possible during the preparedness phase) and subsequent monitoring after implementation. This includes:

- Assessment of the flood situation, including the extent of flooding, vulnerable areas, and the forecasted water levels.
- Development of a flood response plan that outlines the specific areas where the response measures will be deployed, and the quantity of the various materials and equipment required.
- Acquisition of materials and equipment (see also Chapter 12) ensuring that the appropriate equipment and a sufficient supply of materials is available.
- Monitoring of the flood situation and the condition of the emergency measures.
- Maintenance to adjust where necessary and practical to reinforce the flood defences or address any other issues. This may include replacement of worn, damaged, or displaced materials. If replacement might cause a breach of the flood defence or other serious consequence, consider reinforcing the measure with additional materials and/or equipment.

Measure \ Technique	Bulk fill	Sand-bags	Big bags	'Novel' materials	Flash-board structures	Mobile defences	Plastic sheeting	Rock structure	Asphalt / bitumen damage filling (IF time)	Mobile pumps	Explode breach
Raising defence crest											
Raise defence	■	■	■	■	■	■					
Reducing load											
Reduce hydraulic gradient by creating a breach upstream	■	■	■								■
Reduce hydraulic gradient by pumping										■	
Reduce hydraulic gradient by landside embankment	■	■	■								
Increase seepage path by landside berm	■	■	■								
Reduce pore pressures - ring sand boils		■									
Strengthening the defence											
Counterweight / Reduce landside slope steepness	■	■	■								
Reduce saturation of levee							■				
Reduce instability of levee by landside berm	■	■	■								
Erosion protection											
Protect crest/landward surface							■				
Protect waterward surface - directly							■	■	■		
Protect waterward surface - divert flow/waves								■			
Reduce infiltration							■				
Emergency embankment											
Emergency embankment to reduce breach risk	■	■	■								

Figure 11.2: Suitability of various techniques for the measures set out in Chapter 10

11.1 Sandbags / Sandbag systems

As explained already in Chapter 10, sandbags are one of the most common and basic elements used in operational flood fighting interventions, including in the following approaches:

- To build a temporary structure to control the water.
- To add additional water-retaining height.
- To reinforce existing defence structures such as flood embankments when the structure is damaged by the water.

Sandbag structures and reinforcements are a popular choice for use in an emergency because they:

- Are easy to prepare, to handle, to transport and pass on to the target location by people without the use of heavy equipment.
- Can be placed quickly and flexibly.
- Can be used to create robust structures when they are placed in large numbers in the right way in the right place. (Robust sandbag structures are sufficiently large in both the vertical and horizontal direction to allow for the fact that the interconnection between the sandbags is only provided by friction.)

Sandbags are particularly useful when the damage to the defence structure or risk of overtopping due to flood is limited.

Table 11.1: Advantages and disadvantages of sandbags

Advantages	Disadvantages
Functionality proven over many years. Sandbags are commonly used for all types of response measures around the world. Flexible deployment and shapes of structures. Inexpensive and easy to handle and remove. Modest and efficient storage (The bags are stored folded, and sand is taken from nearby sites) No professional knowledge and skills required – allows volunteers to be involved in sandbagging. Low environmental impact • Bags have no environmental impact, • No environmental disturbance caused by sandbag placement • Environment returns to almost the same condition as before when bags removed. • Sandbags of jute or burlap are biodegradable and may be left behind when applied on a turf divot so long as they do not create a problem such as hindering traffic.	Time consuming installation Material and labour intensive. Sand filling may be contaminated after a flood. Sandbags made from plastic: • have friction in only one direction. Therefore, you must be alert when stacking bags on each other. • must be removed after the flood for environmental reasons

11.1.1 Materials

Sandbags consist of only two components: the bag itself and the filling material, each of which has a long history of experience.

Sandbag material. The bags should have a rough texture, be durable and inexpensive, and be resistant to shear and water. To save time in an emergency, it is highly recommended to prepare and use bags with tie-strings attached.

Sandbags made from jute or hessian (a.k.a. burlap) are easy to handle and interlock well due to their rough surface, including under wet conditions. Sandbags made from plastic (PPE polypropylene) show only an interlock in one direction. Note that after the emergency, removal of plastic bags tends to be a lot easier than of decayable alternatives, but plastic bags may be less sustainable (environmentally friendly).

Sandbag sizes. Different sizes of sandbags are available, although a typical size is about 0.3 m by 0.6 m or 0.4m by 0.6m. Bags are easier to handle and carry if they weigh about 10 to 15 kg. This kind of weight allows inexperienced volunteers such as teenagers and older people to keep working.

Filling material. The ideal filling material is sandy soil. Clayey and silty soils are difficult to fill. Gravelly soils may be too permeable for some situations but are well-suited for giving extra weight and for measures where good drainage is of high importance. If the sandbags can be filled and stockpiled beforehand (e.g. at a depot), a particle size of 0.063 to 0.8 mm is recommended. However, in practice in an emergency the material/sand that is available at the site at that moment may have to be accepted; particle sizes cannot be measured in those situations. It should be appreciated that compaction of the sandbag structure by treading down the sandbag layers has more effect on any required water imperviousness than using a certain particle size distribution.

11.1.2 Filling and closing

Completely-filled sandbags are difficult to lift and shape. Instead, bags should be filled to about two-thirds (2/3) of their capacity as shown in Figure 11.3. A 0.4m by 0.6m sandbag, filled to 2/3, weighs about 15 kg (if the sand is wet, more like 20 kg).

To minimise time pressure during an emergency, sandbags can also be filled in advance and kept in storage ready for use. However, once in the response phase, it is necessary to check that there is no damage to the bags that could result in leaking of sand. Damaged bags should be removed as the sand volume in the bag will diminish and the sandbag will lose its functionality.

After filling, the top of sandbag can be closed in two main ways:

(a) With a zip tie to stitch up or to knot the opening of the bag. The tie should leave two hands' width of space above the filling to allow the bag to be shaped correctly.
(b) If closing or sealing of the sandbag is not possible, fold the top of the sandbag at an angle and place it under the bottom of another sandbag. When only folding back the top side, there is a higher chance of the sandbag becoming empty in the wake of a small displacement, leading to loss of stability of the whole construction.

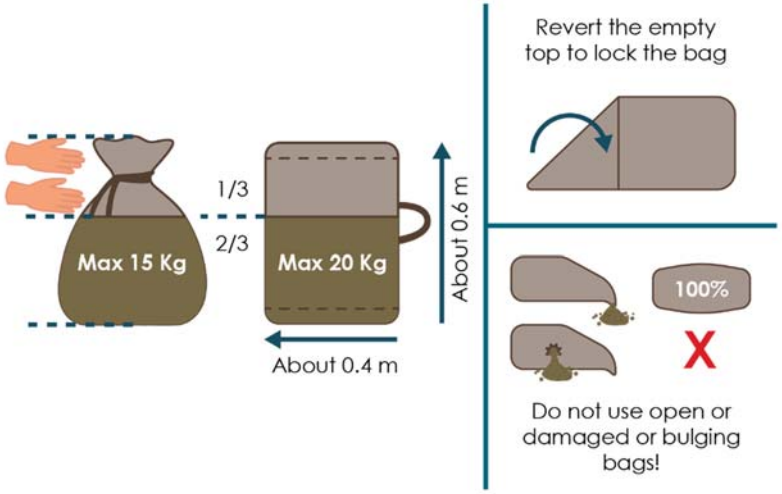

Figure 11.3: Size and filling of a sandbag (adapted from Working instruction for sandbags – presentation train the trainer 15-03-2023 by Dutch Working Group Professionalization Dike Inspection)

The amount of filling should be as uniform as possible:

- To avoid problems when handing over and placing the bags. (The handling person adapts their approach (including body tension) to the weight they expect to receive, whereas if they receive sandbags of different weights, they are likely to get tired very quickly, muscle pains can develop (e.g., in the back) and mistakes can be made.)
- To allow good packing and sealing during placing, so that the sandbags can nestle close to each other. (If sandbags are filled to different amounts, it may well be difficult to achieve a good connection between the bags.)
- To prevent uneven layers.
- To prevent sandbags rolling away down a slope.

For these reasons, different types and sizes of bags should be kept separate, being moved and placed by separate chains of people.

Manual filling of sandbags.

Sandbags should be filled by two people. One person should place the bottom of the empty bag on the ground and hold its neck so that the other person can fill the bag with sand (see Figure 11.4). Typically, 10 workers can fill 500 bags per hour without tying up the opening.

Figure 11.4: Filling a sandbag by two people, using a scoop (source: Flood Defence Manual published by MLIT Japan)

Mechanical filling of sandbags.

Sandbags can be mechanically filled using a sandbag machine with a hopper (see Figure 11.5). Sand is loaded into the hopper using a mechanical shovel unit and the machine is pre-programmed to produce sandbags of a required weight. Each bag is dropped off the machine and then manually tied up before being loaded onto a pallet for distribution. Using a filling machine has the following advantages:

- Faster filling and sewing up of the sandbags.
- A standard and consistent weight for each sandbag.
- Reduced manual handling.

However, experience to date suggests that these machines may be subject to periods of downtime, and thus an increase in performance compared to manual filling is not guaranteed.

Figure 11.5: Sandbags mechanically filled using a hopper and a mechanical shovel (source: Environment Agency)

11.1.3 Transport, handling and placing

Transport the filled sandbags to the site to be protected. Ideally, the bags should be filled as close as to the site as possible. In terms of manual handling, in one hour, a single worker can typically carry 80 bags a distance of 10 m, including picking up, transporting, and laying down). However, chains of handling are often more effective.

Sandbag handling chains

Stand facing one other when passing on sandbags (see Figure 11.6). Allow one person per meter in a 'chain' of people and stand in order of height, keeping the sandbag close to your body. When you are standing on a slope, put a bag under your lower foot so that you can stand and work upright. To transport bags down a slope, use plastic sheets as a sort of slide.

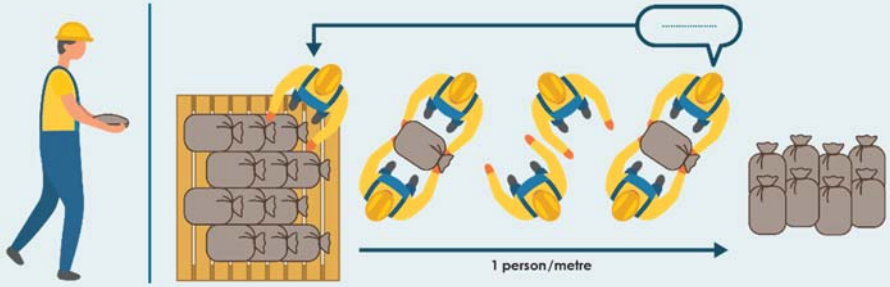

Figure 11.6: Passing on sandbags (source: Working instruction for sandbags – presentation train the trainer 15-03-2023 by Dutch Working Group Professionalization Dike Inspection)

During placing, care is required to ensure the correct orientation of different types of sandbags. Place sandbags such that the greatest shear resistance is at right angles to the water load, see Figure 11.7. With jute/hessian bags there is good friction in both directions, whereas for plastic bags with handles there is normally a single direction giving the best shear resistance; normally the position of the handles/noose gives an indication of the required placing direction.

When layering sandbags, place the sandbags such that there is 'half brick' overlap between layers or pairs of layers. (The white arrows in Figure 11.7 show where to place the bag.)

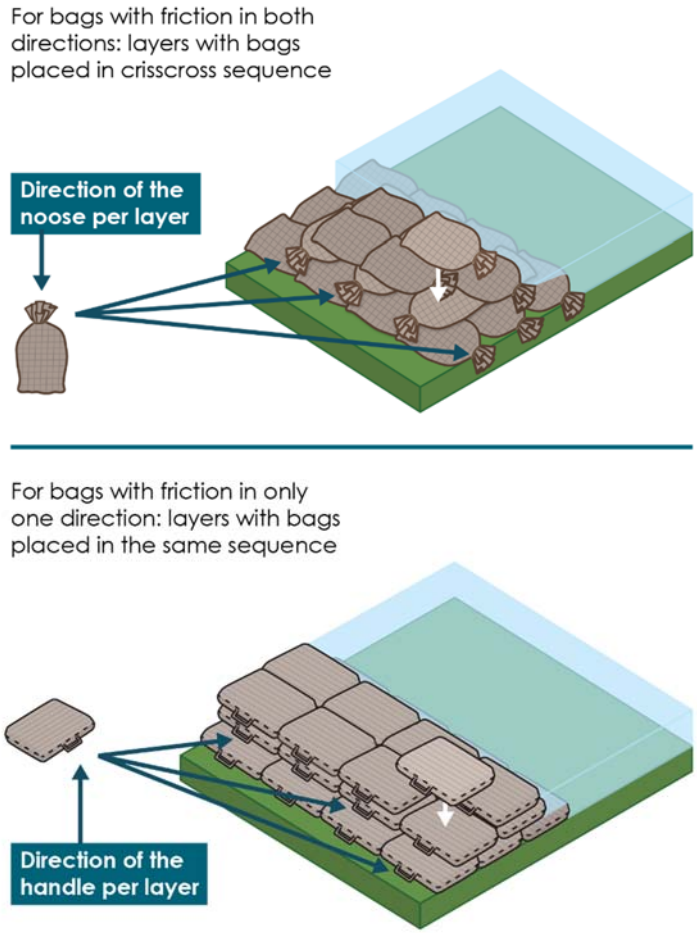

Figure 11.7: Correct placement of sandbags, made from burlap with friction in two directions (left) and from plastic with friction in only one direction (right) (adapted from Working instruction for sandbags – presentation train the trainer 15-03-2023 by Dutch Working Group Professionalization Dike Inspection)

Forming a sandbag embankment

Place the sandbags lengthwise and parallel to the direction of flow to form an embankment, using staggered multiple lines of sandbags to ensure strength (see Figure 11.8). Layer the sandbags such that the lower one or two layers are always one bag wider than the upper one or two layers (see Figures 11.9 and 11.10). This makes it possible to enlarge the stack in a triangular shape.

The orientation of the bag should be such that the tied-up end of the bag points to the waterside and the bottom of the bag to the landside. Subsequent bags should be placed on top, offset by half length of the previous bag.

Help to keep the embankment watertight by treading down each sandbag layer after placement.

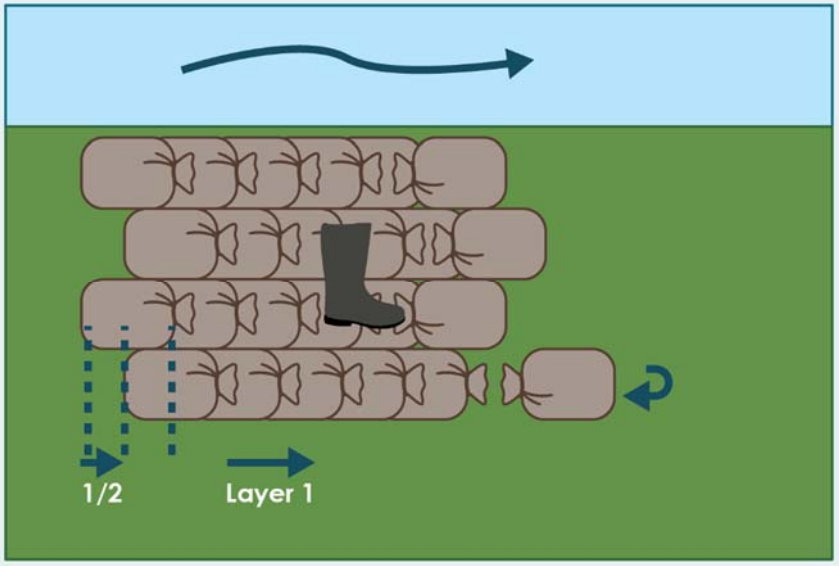

Figure 11.8: Placement of several sandbag rows when building a river flood embankment (adapted from Working instruction for sandbags – presentation train the trainer 15-03-2023 by Dutch Working Group Professionalization Dike Inspection)

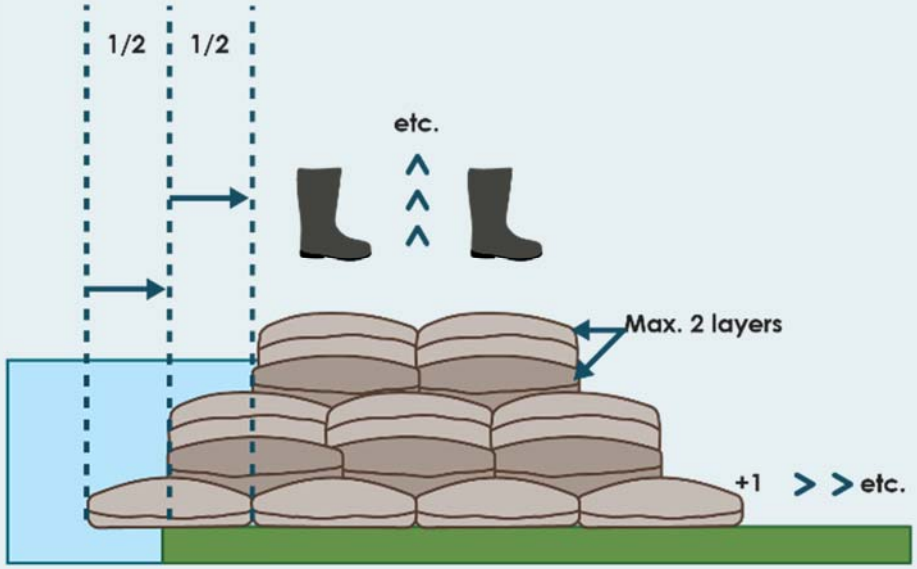

Figure 11.9: Placement of several sandbag layers when building a river flood embankment (adapted from Working instruction for sandbags – presentation train the trainer 15-03-2023 by Dutch Working Group Professionalization Dike Inspection)

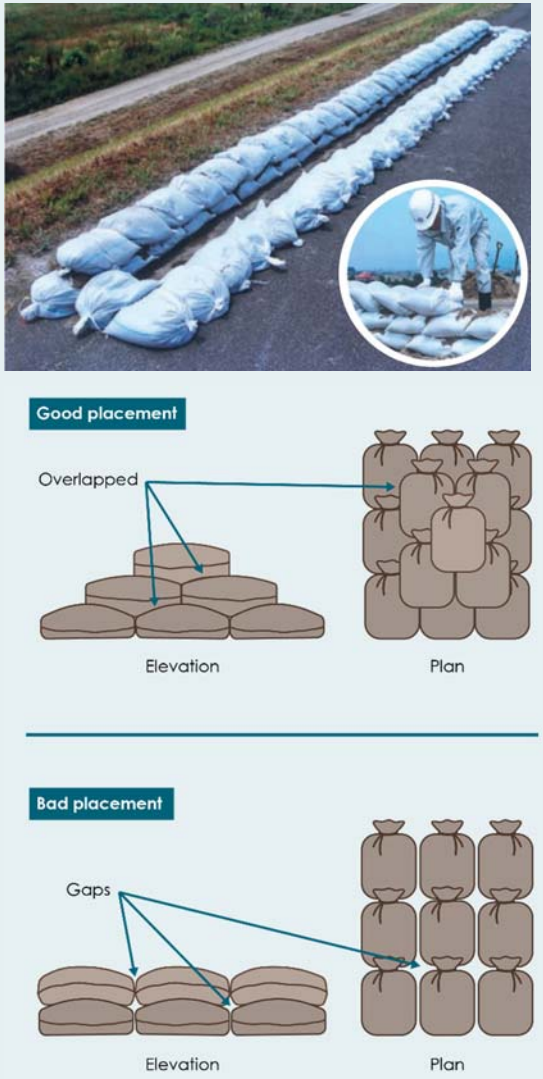

Figure 11.10: Sandbag placement (source: Flood Defence Manual published by MLIT Japan)

11.2 Big bags

Big bags are also known as Super Sacks, Dumby Bags, or large sandbags. Big bags are large flexible bulk containers that hold materials, including sand. They provide an efficient way to fill large gaps without needing excessive labour or materials compared to traditional sandbags. Five big bags will provide 4.5m of defence length, replacing 750 traditional sandbags. In addition, the big bags may be used on uneven surfaces and curved alignments.

As already illustrated in Chapter 10, big bags can be used effectively in flood control and emergency flood mitigation efforts. Overall, big bags are versatile and widely used in flood control efforts due to their convenience, efficiency, and durability. Their functionality helps streamline flood response and mitigation operations, save time and resources, and ensure the safe handling and protection of communities and infrastructure during flood emergencies. The main ways in which big bags are commonly used in flood situations include the following:

- Defence raising (see Section 10.2).
- Strengthening the defence (see Section 10.4):
  - Used as embankment toe counterweights to prevent instability.
  - Protecting infrastructure: Big bags can be placed around critical infrastructure like power substations, water treatment plants, and roads to prevent flood damage (see Figure 11.11).
  - Flood gate closure**:** Big bags can be used to seal off openings, such as drainage gates or culverts, to prevent water from flowing into certain areas.
- Erosion control (see Section 10.5) In addition to flood control, big bags can be used for erosion control along riverbanks or coastlines. They help stabilize soil and prevent further erosion during floods and for closing a gap or breach.
- Temporary defences (see Section 10.6). Big bags are often used to create temporary flood defences. They are filled with sand, soil, or gravel and strategically placed to redirect or contain floodwaters, protecting homes, infrastructure, and communities. Specific examples include:
  - Temporary flood barriers for homes: Residents in flood-prone areas may use big bags to create temporary flood barriers around their homes to protect against rising floodwaters.
  - Redirecting water: Big bags can be used to redirect floodwaters away from critical infrastructure, neighbourhoods, or agricultural land (see e.g. Figure 11.12). They can help guide water to safer areas or drainage systems.
- Breach closure. (see Section 10.7) Big bags can be used as part of a breach closure strategy, so long as they do not apply too much load to the existing embankment.

Figure 11.11: Closure of an underpass with big bags (left) and subsequent sealing with plastic sheet (right) in Mook, The Netherlands (source: Regional Water Authority Rivierenland)

Figure 11.12: Big bags used to divert water for a flood embankment repair (source: USACE)

11.2.1 Materials

The size of big bags is typically 0.9m by 0.9m at the base, with a height of 0.9m to 1.2m.

The exact choice of materials and construction methods may vary depending on the manufacturer and the specific intended use of the big bags. However, they are commonly designed to provide a strong, durable, and water-resistant barrier that can effectively contain floodwaters and protect communities and infrastructure during flood emergencies. Typically, big bags have the following elements:

- **Outer shell**: The outer shell of big bags flood barriers is typically made of a thick, heavy-duty, woven polypropylene fabric. This fabric is designed to be strong, tear-resistant, and water-resistant. It provides the primary structural integrity of the Super Sack and protects the contents from environmental elements.
- **UV stabilization**: Many big bags are treated with UV stabilizers to protect them from the damaging effects of prolonged exposure to UV radiation in sunlight. The stabilizers absorb or deflect UV rays, preventing them from breaking down the molecular structure of the material. As a result, the bags remain strong and resilient even

Table 11.2: Advantages and disadvantages of big bags

Advantages	Disadvantages
Rapid deployment. They can be deployed rapidly, especially if there is a pre-existing supply of empty bags and equipment for filling them. Rapid filling and stacking. They can quickly be filled with locally available materials and stacked to create a barrier or counterweight. Easy to transport and position with mechanical equipment attached to their lifting loops or straps, even in challenging conditions. (This reduces the physical strain on emergency responders and volunteers.) Flexible and stable: When properly filled and stacked, big bags can provide a stable and reliable barrier on various types of terrain, including flat surfaces, sloped areas, and riverbanks. Existing or new defences: They can be used to reinforce existing flood defences or create new defences. Cost efficient: As long as necessary equipment is readily available, big bags are more cost-effective than traditional sandbags, their durability and resistance to UV degradation allowing them to be stored and reused in multiple flood events.	Need vertical support: Stacking big bags vertically without other support may lead to inundation of the embanked area. Need for lifting and transportation equipment. The size and weight of big bags (much larger than traditional sandbags) means that they require the proper equipment for transportation and placing / replacing. For placement of big bags with helicopters it may be necessary to use extra strong big bags.

when exposed to sunlight for extended periods. Without UV stabilization, the bags would deteriorate quickly, compromising their effectiveness in holding materials securely.

- **Seams and stitching**: The seams of big bags are usually reinforced with strong stitching to prevent leakage and ensure that the bags can hold the weight of the filling material.
- **Lifting loops or straps**: Big bags are equipped with lifting loops or straps made from the same durable material as the outer shell. These loops or straps are used by machinery to lift the bags for loading/unloading and for positioning the bags during deployment.
- **Separate filling spout or chute**: Big bags designed for flood control are filled via a bespoke discharge spout or chute (see Figure 10.13). This allows for controlled input of the filling material and helps create a stable barrier when the bags are stacked.

Figure 11.13: Big bag filling chute used to fill bags on site at a flood embankment project in Skagit County, WA, USA (source: USACE)

Additional optional features include:

- **Internal liner**: An internal liner made of polyethylene or another water-resistant material. This liner adds an extra layer of protection against moisture and helps prevent leakage of the contents.
- **Tie-Downs**: Big bags may have tie-downs or fasteners to secure them in place under high water conditions when they are deployed as flood barriers.
- **Chute features**. These are used for filling and/or emptying as illustrated in the different designs shown in Figure 11.14

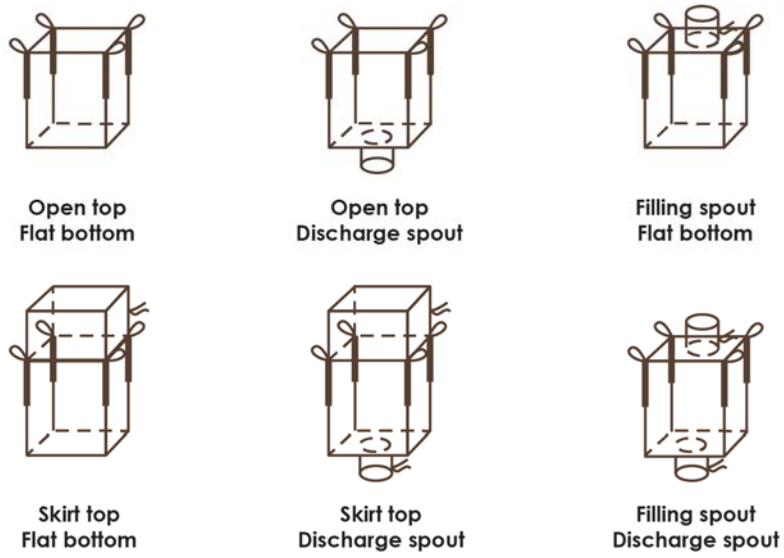

Figure 11.14: Different designs of big bags (source: U.S. Army Corps of Engineers Flood Manual)

Multiple big bag unit systems

Although big bags may come as individual bags, it is also possible to obtain them in connected sets, typically 5 m or longer. They can be deployed quickly and filled on site using a mechanical shovel unit adjoining each other to create continuous defence lengths.

As an example, units provided in 10 m long fold-out strips, containing ten 1m cube size bay have been deployed in the UK (see e.g. Figure 11.15). They have mainly been used in high wave-energy situations to prevent breaches in defences and to protect equipment on beaches. They are more robust in such situations than metal-framed temporary barriers.

Figure 11.15: Big-bag style gabions used for temporary flood protection on a beach in Cornwall (source: Environment Agency)

11.2.2 Filling

Implementing big bags in flood control and in an emergency response measure involves several typical implementation steps:

1. **Assemble materials and equipment**. Gather the necessary equipment required for filling big bags, such as shovels, loaders, and the appropriate fill material (e.g., sand or soil).
2. **Safety precautions**: Ensure that all personnel involved in the deployment of big bags are aware of safety protocols.
3. **Filling process**: Open the big bags and place them in the desired locations. Fill the big bags with sand or soil, taking care not to overfill to allow for proper closure. Where built-in ties or closures are part of the big bag design (see Figure 11.14), seal the bags, securely closing and fastening them.

11.2.3 Transport, handling and placing

Attach the lifting loops or straps to lifting machinery (trucks, helicopters etc) when handling the big bags. This includes when moving the filled big bags on or off any intermediate transport and when moving them to their designated positions (see Figure 11.16).

Figure 11.16: Big bags transported via helicopter (Source: U.S. Army Corps of Engineers Flood Manual)

Place the big bags in a staggered and interlocking pattern to create a stable structure. Ensure that they are aligned to redirect or contain floodwaters effectively. When stacking higher than one tall, they should be stacked in a triangular shape when possible (see Figure 11.17). If stacking vertically, additional support (see Figure 11.18) is likely to be required to avoid displacement of the bags during high water conditions.

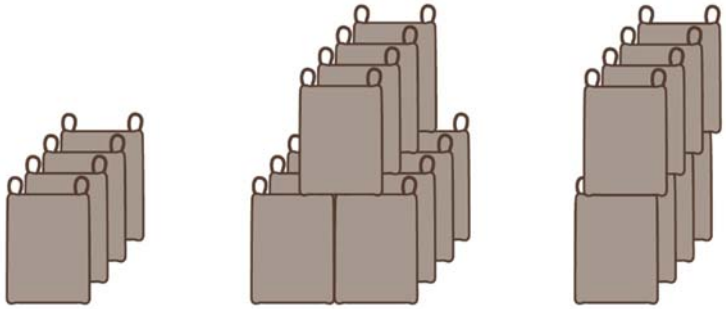

Figure 11.17: Stacking configuration of big bags (source: U.S. Army Corps of Engineers Flood Manual)

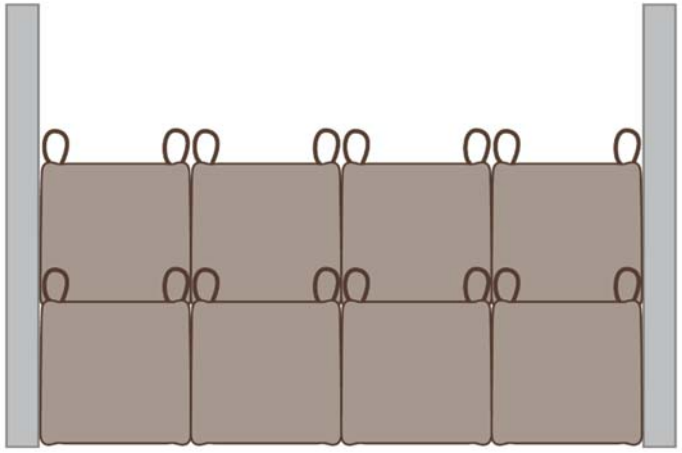

Figure 11.18: Supported stacking of big bags

After placing the big bags, stabilize and compact them by using equipment or tools to ensure they form a solid barrier. This may involve tamping the bags gently.

11.3 Mobile flood defence systems

Mobile flood protection systems can be classified into location-bound (demountable) and location-independent (temporary) systems. Location-bound systems require a permanent foundation (see Figure 11.19) or anchor points for sound installation, which are not required for location-independent systems.

Location-bound systems are suited for situations where flood events are expected to occur regularly. They can also be used for closures in flood walls and embankments, including temporary closures of railroads or roads (see Figure 10.19, right).

Figure 11.19: (left) Foundation of a location-bound system in Krynica Morska, Poland; (right) Construction of a closure with stop logs under a bridge in Mook (source/left: Eric van Kuijk) (source/right: Regional Water Authority Rivierenland)

Because of the need for foundations or anchors, location-bound systems must be designed and fabricated to match the exact requirements of the site. It is also necessary to be able to store the systems near the site

and conduct regular exercises in deployment. As location-bound defences are part of the designed flood defence system, they are not considered to be emergency response measures in this handbook. This section therefore focuses on location-independent mobile flood protection systems.

Location-independent systems generally focus on local raising of the defence height rather than dealing with any other failure mechanism for the permanent defences. These are fully mobile and can be applied at different locations without any pre-installed facilities. They are brought from a central storage space and assembled at the site of operation as required.

Location-independent systems are more suitable for lower protection heights between 0.6 m until 1.0 m. A relatively low protection height for the system assists in limiting the risk of failure due to unknown factors (e.g. the load-bearing capacity of the ground.) Within these constraints, the systems can be used flexibly (although the ground often needs to be flat and level) and can often be used without specific design and detailed pre-planning.

Location independent systems can generally be installed in a significantly shorter time and with less effort than the installation of an equivalent traditional sandbag dam. Accordingly, using these systems a much greater length of flood defence in a much shorter time than an equivalent sandbag dam. For health and safety reasons, the weight of the individual components of the location-independent mobile defences should not exceed 30 kg. If many components need to be handled and installed, the weight of a single component should not exceed 20 kg.

Location-independent mobile systems are also generally reusable. This is also due mostly specific conditions, where they can be applied.

Table 11.3: Advantages and disadvantages of location-independent mobile defences'

Advantages	Disadvantages
Location-independent mobile defences can be set up over a longer length in less time and with less personnel than with sandbags. Generally reusable when properly stored and maintained.	Systems vary considerably in the degree to which their functional capability has been proven. This creates a challenge when seeking to make an evidence-based choice for use in emergency situations and tends to encourage use of the better-tested systems High initial investment costs. More requirements in terms of training of personnel and availability of equipment for deployment. Ground conditions limit the type and suitability of the system that can be applied at a target location. Risk of vandalism, theft, or damage from external influences.

Location-independent mobile systems may be classified as shown in Figure 11.20, with examples of these systems illustrated by the images in Figure 11.21.

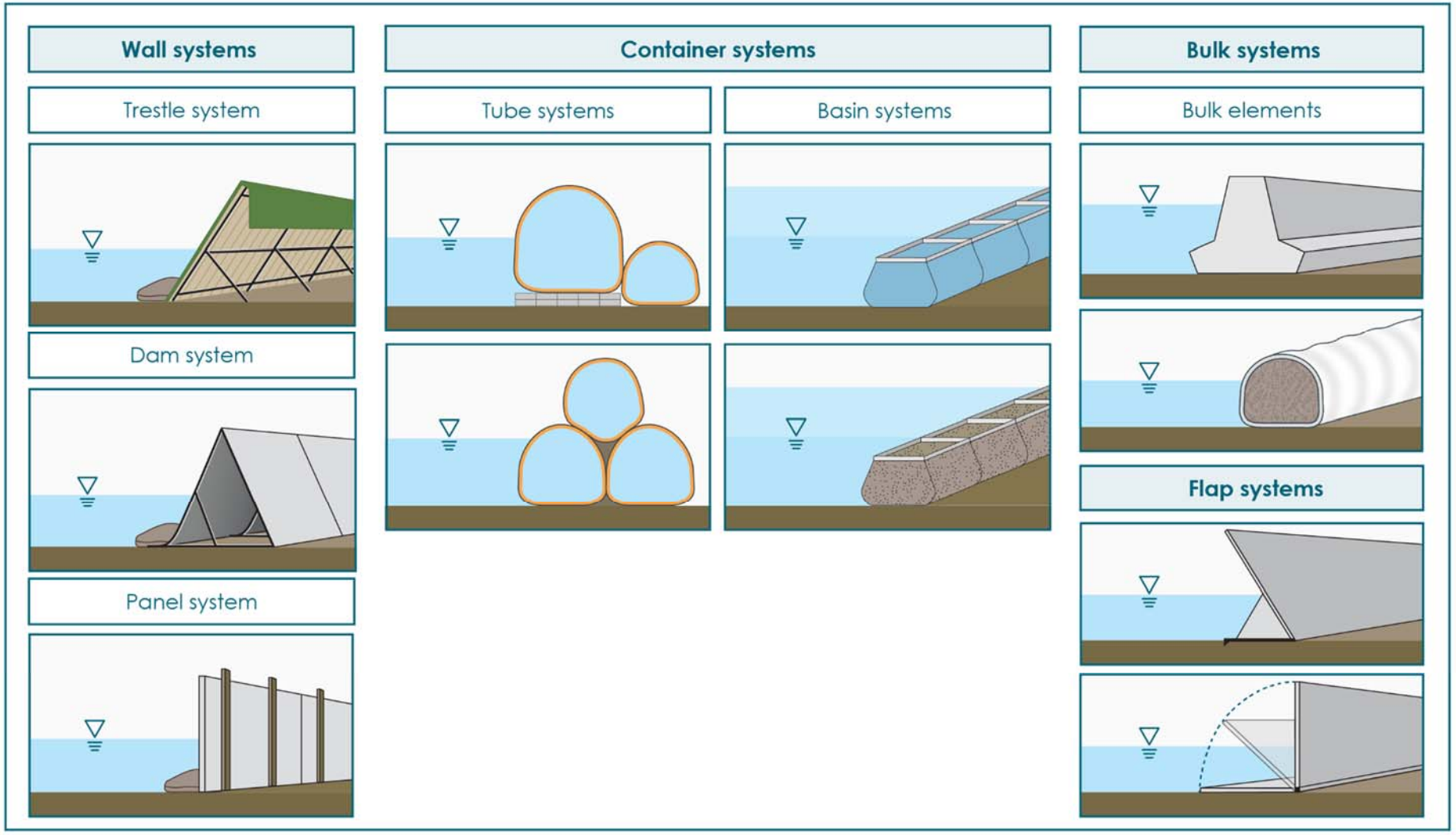

Figure 11.20: Classification of mobile location-independent flood protection systems (adapted from Massolle et al., 2018)

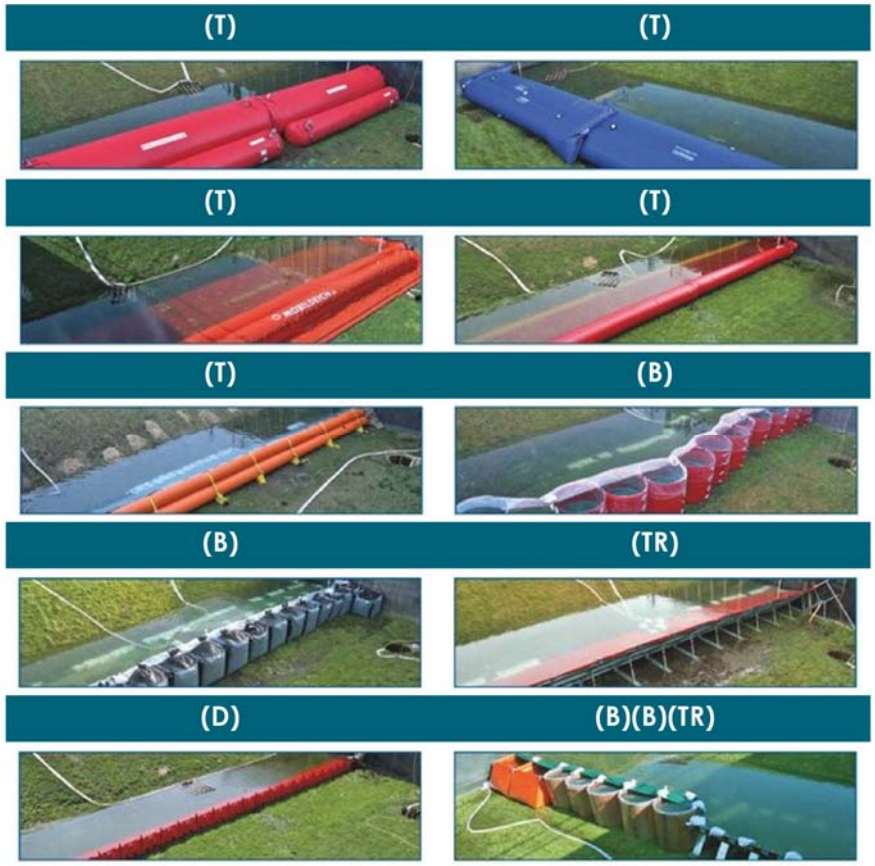

Figure 11.21: Various location-independent mobile systems: (T) Tube system, (B) Basin system, (D) Dam system, (TR) Trestle system (source: Masolle et al, 2019, Sandbag Replacement Systems – Stability, Functionality and Handling)

The available systems may be grouped as follows:

- Container systems (tube and basin systems) which counteract the horizontal water pressure by the weight of their filling material, such as water or sand (see e.g. Figure 11.22).
- Air-filled tube systems, which are held in place by static friction caused by the flood water, resting on force-fit connected plastic aprons laid horizontally on the ground.
- Flap systems, trestle systems and dam systems, which use the vertical water pressure with their geometry to withstand horizontal water pressure.
- Bulk systems, which use high-density materials such as sand or gravel with a confining membrane or concrete.
- Panel systems, which consist of panels fastened to stakes, driven into the ground on alternate sides of the panels.

The probability of failure of a location-independent protection system depends on its structural and geotechnical stability and the feasibility of a correct and safe installation.

In terms of stability, 5 failure modes can be distinguished:

- Sliding (as well rolling).
- Overturning.
- Loss of stability (due to insufficient construction, overload, or vandalism).
- Leakage.
- Geotechnical failure.
- Vandalism linked to any of the above.

The feasibility of a correct and safe installation depends on the:

- Available lead time to secure the operational readiness of the crew, the transport of materials to the location and the erection of the system.
- Static and dynamic loads due to water level, waves, ice pressure and the solid content of the water and impact loads due to flotsam.
- The number of available and trained personnel who are familiar with the selected mobile flood defence system and the way it is assembled and installed.

- The manageability of the components under heavy meteorological circumstances are determining factors.

Figure 11.22: Water inflated cofferdam (source: https://detroittarp.com)

Use of A-frame trestle flood protection systems in the UK

A-frame barriers are widely used in the UK. The Environment Agency in England has moved away from using sandbag walls as a flood protection measure and now considers such A-frame barriers to be more effective than other available techniques. Reaching this conclusion involved:

- Gaining a full understanding of how the barriers operate.
- Rigorous testing using various deployment method in both simulations and during actual flood events.
- Using the testing to select deployment methods that have made these temporary defences more reliable.

Deployment methods that have made the barrier more reliable include:

- Addition of a plastic membrane over the front of the barrier extended over the ground on the waterside by 2m to create an apron. The weight of the flood water on this apron performs a key role in ensuring the stability of the defence.
- Bracing the A-Frame barriers on the landside against roadforms, in turn braced against concrete blocks (see Figure 11.23) The addition of the concrete blocks has proved to be an important additional safety measure to prevent sliding of the barrier under load.

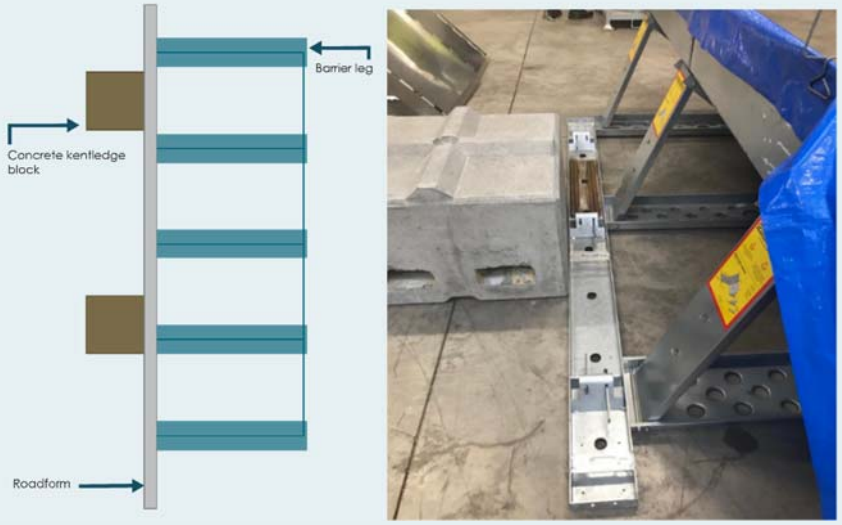

Figure 11.23: Bracing of A-Frame barriers (source: Environment Agency)

As an example, the A-Frame barriers were deployed around Walham Power station in the UK (see Figure 11.24) following significant flooding of

the Severn River in 2007. This was the first time this barrier was used in the UK and protected the power supply to 500,000 homes.

Figure 11.24: A-Frame barriers deployed around Walham Power station in the UK following significant flooding of the Severn River in 2007. This was the first time this type of barrier was used in the UK. This Critical National infrastructure provided power to 500,000 homes (source: Environment Agency)

11.4 Mobile pumping systems

Mobile pumps may be used in the following situations:

- When overtopping of a permanent flood defence is expected, in order to reduce the load on the defence.
- When a pumping station is offline for repairs or maintenance.
- To pump out flooded areas after an event.
- To address seepage through and ponding behind temporary flood defences, generally using smaller pumps.

In deciding to use a mobile pump, it is important to avoid any problematic consequences, such as:

- Damage due to surface erosion at the point of discharge of water.
- Instability of the waterside of the flood embankment arising from rapid draw-down of water levels in the watercourse. Such rapid draw down may arise where high volumetric capacity pumps are installed in a small water system.
- Piping through or under the flood embankment when water levels are lowered in the flooded area on the landward side of the embankment.

11.4.1 Pump selection

The selection of the type of pump to be used is governed by several factors:

- The required capacity of the pump:
  - The height or “head” difference over which the water needs to be pumped.
  - Required volumetric rate of water pumping.
  - Distance water needs to be pumped.
- Restrictions on the use of the pump:
  - Minimum water depth at the location of water extraction.
  - The weight of the pump and the degree of vibration, since this can cause damage when placed on a flood embankment.
- The location of the operation:
  - Access to site often constrains the type and size of pump that can be used.
  - Availability of power (e.g. electricity, diesel)
- Where the water is to be discharged.

In choosing the right pump for the job, manufacturers' pump performance curves must be consulted to determine whether a given pump is able to work efficiently given the head and discharge pipe length that a site presents. Common types of mobile pump include diesel end suction and electric submersible:

Diesel end suction pumps can provide suction head (vertical distance from the water surface to the pump) of up to about 3 m. As shown in Figure 11.25, suction pumps can theoretically work up to about 85% of full atmospheric head (i.e. about 8.8m) but in practice they are not efficient beyond about 3m.)

The pumps come in self-contained units that can be deployed on ground level direct from a vehicle without mechanical lifting. They are often deployed with a separate fuel cube to provide fuel for sustained operation. They may be:

- Trailer mounted (up to 20 cm pipe size / 300 l/s discharge rate, approx. 1.5 tonnes) which can be deployed quickly; or
- Sled-mounted (up to 60 cm pipe size / 1.65 m³/s discharge rate, 11 tonnes).

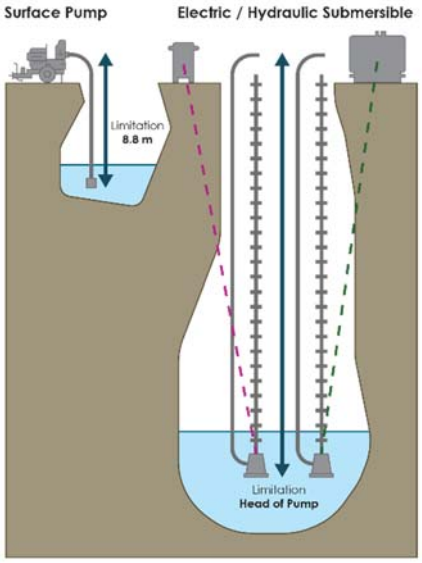

Figure 11.25: Diagram showing the relative suitability of suction and submersible pumps (source: Environment Agency)

Example use of a diesel end suction pump, Kent, UK

While a UK pumping station was being upgraded, a.60 cm diesel end suction pump was deployed (see Figure 11.26). The discharge pipework was bolted, and a fuel cube was mobilised (in front of the pump in the picture). Note In the foreground some additional 30cm discharge pipes with Anfor lever couplings.

Figure 11.26: 60 cm mobile diesel end suction pump deployed in Kent, UK (source: Environment Agency)

Electric submersible pumps sit in the water to be pumped and work entirely by pushing water rather than sucking it. Not being constrained by suction limitations, they are more efficient and can generally achieve higher heads, the maximum head only being limited by their own capabilities (see Figure 11.25). The pumps come in a wide range of sizes, typically up to 60 cm pipe size / 1.2 m³/s discharge rate, weighing approximately 7 tonnes.

Electrical submersible pumps (see e.g. Figure 11.27) may be powered from a normal electricity supply (e.g. when used at an existing pumping station to augment or provide contingency for the permanent pumps). However, in most emergency situations such a supply is not available and so distribution and starter panels and an electric generator will need to be deployed as well. In this case, to ensure they remain operational during a flood event the electric panels and generator must be kept above flood level. If there is no suitable high ground, they can be placed on a vehicle trailer or protected with sandbags or big bags. The generator usually has a large onboard fuel tank but can also be recharged from a fuel cube. Research is underway to explore the use of hydrogen fuel cell-powered generators to reduce carbon footprint.

Figure 11.27: 60 cm electric submersible pump on a sled about to be lifted in upstream of a pumping station (source: Environment Agency)

11.4.2 Deployment process

Pump deployment comprises four stages:

1. **Site establishment**. This involves visiting site and designing the pump and pipework layout, establishing perimeter fencing, traffic management, welfare facilities, identifying a safe system of work on site and briefing the deployment team. Organising the site layout includes:
   a. Ensuring space for turning circles for heavy goods vehicles and for crane pads.
   b. Ensuring adequate access tracks. In certain situations, and for some pump types/sizes, temporary access tracks or a lifting pad will need to be constructed using trackway or aggregates on a geotextile base.
   c. Careful selection of the discharge point for water to prevent erosion of soft ground. Scour protection and/or a directed discharge may be necessary.
   d. A safe site layout for fuel cells, control panels, electricity supply cabling, etc, which keeps them away from rising flood waters
   e. A site layout which keeps operatives safe from slips trips and falls.
2. **Deployment**. This involves bringing the equipment and pipework to site and installing the pumping system. Note the following:
   a. Small (e.g 15 cm) pumps can be deployed by 2 operatives and a 4 x4 vehicle.
   b. The larger pumps require significant resources to deploy and often need lifting plans from a qualified lift supervisor which can be a challenge when resources are stretched.
   c. Larger pumps of 30 cm and above require adequate water depth at the point of water extraction and once in position are generally fixed in that location so it is important that water can be flow freely to the pumping location.

d. 30 cm and smaller pipework is easy to manhandle and assemble but 60 cm pipework needs to be lifted mechanically and bolted together. Discharge pipes should be properly secured and have the appropriate (timber) block support in place.
e. Submersible pumps are generally deployed by lifting into the watercourse from which the water is to be pumped. Deployment therefore requires loader cranes and suitably firm ground to deploy them.
f. When deploying a submersible pump, a connecting section of pipework should be pre-attached (see Figure 11.28) so that any remaining pipe connections can be made in a safe, dry environment and nobody needs to work over or on the water.

3. **Operation**. This includes operating the pumps, maintaining the installation, and refuelling the pumps/generators as necessary. For larger pumps, this may require significant training. For smaller end suction pump units up to 15 cm, operation is simple and only requires training on refuelling the pump safely and ensuring that there is sufficient water to avoid drawing air into the pump.
4. **Demobilisation**. This involves dismantling the pump installation and reinstating the site including removing any filling, bag work or trackways.

Ideally for pumps of 30 cm pipe size and above there should be pre planned operational plans for asset failures or areas of frequent overtopping. This greatly reduces the time needed for the Site Establishment phase.

Figure 11.28: A 60 cm submersible pump with attached pipework being lifted in by crane (source: Environment Agency)

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CHAPTER 12

Logistics and implementation

Key messages:

- **Understand resource needs for emergency response**
- **Balance resource needs and availability in response**
- **Material resources are critical**

Figure 12.1: Structure of the handbook

Other places to find information on the topics of this chapter

Chapter 2: organizational context within which implementation takes place

Chapter 3: basic principles of preparedness, including early warning needs for effective emergency operations

Chapter 4: basic principles of response that form the foundation for effective logistics during flood emergencies

Chapter 5: types of threats to be considered in logistical planning of emergency response

Chapter 7: communication strategies and tools for coordinating flood response

Chapter 8: assessment and inspection techniques relevant for planning and optimizing logistical operations

Chapter 9: failure mechanisms to be considered in logistical planning of emergency response

Chapter 10: information on flood defence repair and reinforcement measures along with their logistical requirements

Chapter 11: essential resources and equipment for emergency measures

Chapter 13: health, safety and wellbeing protocols in emergency logistics

Chapter 14: the role of reliability analysis in understanding how to improve logistics and implementation

Chapter 15: understanding of logistics and implementation and resulting capacity building needs

Chapter 16: understanding the required capacities and capabilities for logistics and implementation that need to be funded

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Note:

The Reader is kindly requested to take note of the Disclaimer on page ii of this handbook.

Chapter title page photograph:

Sorting out the logistics for implementing big bags (courtesy: USACE)

Key messages:

- **Understand resource needs for emergency response**. Effective emergency response hinges on a thorough understanding of the required resources (personnel, equipment, and materials). Identifying needs and ensuring the availability of these resources is crucial.
- **Balance resource needs and availability in response**. Emergency response organizations can bridge the gap between resource needs and availability by conducting desktop assessments of field exercises based on flood event scenarios.
- **Material resources are critical**. During emergency response, materials play a pivotal role in addressing immediate needs and supporting recovery efforts. Of utmost importance are materials used for forming temporary barriers to control or redirect floodwaters.

This chapter starts in Section 12.1 by providing an overview of logistics and implementation. The chapter then explores:

- Section 12.2 – emergency action planning during the preparedness phase.
- Section 12.3 – resources required for emergency management of flood defences.
- Section 12.4 - how resource needs can be balanced against availability.
- Section 12.5 – transportation logistics.
- Section 12.6 – the need for real time decision making within the dynamics of a rapidly evolving situation supported by (Section 12.7) ongoing monitoring and evaluation.
- Section 12.8 – implementation of the recovery phase.

12.1 Overview of logistics and implementation

Flood defence logistics and implementation refer to the coordinated actions and processes put in place to respond to and manage flood events, particularly those involving flood embankments. In the context of the logistics and implementation of managing flood embankments, the primary goal is to protect lives, property, and the environment in the event of a flood embankment breach or a significant increase in water levels (see e.g. Figure 12.2). For flood defence emergency managers, this involves a systematic approach that includes:

- **Emergency response coordination:** Activation (with other stakeholders) of the Emergency Operations Centre (EOC) to oversee and coordinate all response efforts, ensuring a coordinated response to the flooding event and efficient allocation of resources. This includes:

- Coordination with utility companies to manage shutoffs of gas, water, electricity, and other utilities to prevent hazards.
- Addressing potential environmental concerns and hazardous material spills arising from the flooding.
- Management of information flow to the media and the public to ensure that accurate and timely information is disseminated.

- **Assessment and monitoring:** Continuous monitoring of the flood situation, including water levels, the condition of the flood defence, and the extent of flooding.
- **Resource management:**
  - Deployment of necessary resources, such as personnel, equipment, sandbags, and machinery, to address the flood and reinforce or repair the flood defence.
  - Establishment of staging areas near the affected areas to store resources and equipment, making them readily available for response efforts.
  - Management of resource requests and distributions to ensure that available resources are efficiently allocated where needed.
- **Flood defence repair and reinforcement:** Activation of flood defence repair crews to address breaches, stabilise flood embankments, and prevent further damage to embankments and structures (for details see Chapters 10 and 11), ensuring they have the equipment and materials they need.
- **Documentation and reporting:** Maintenance of detailed records of actions taken, resource usage, and incident reports for future reference and post-event analysis.
- **Recovery planning:** Beginning planning for the recovery phase, which includes damage assessment and long-term flood embankment repair and infrastructure improvements.

As already explained in Chapter 2, flood response typically involves three distinct phases: preparedness, response, and recovery (Figure 12.3). Each phase has its own logistics and implementation requirements.

Figure 12.2: Floodwaters from the burst Kinugawa River (left) flow into a residential area (right) in Joso, Ibaraki Prefecture, Japan, 2015 (source: NPR)

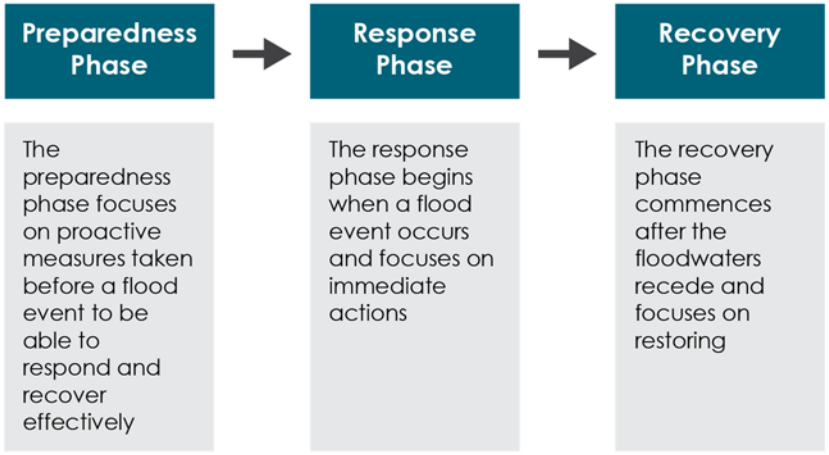

Figure 12.3: Phases of flood response

12.2 Emergency action planning

No two flood events are the same. Nevertheless, there are some common planning and preparedness steps that can be taken by a flood defence emergency manager to prepare for a flood event.

Emergency action plans, prepared by flood defence emergency managers in collaboration with stakeholders, focus on the steps and actions that need to be taken during an emergency, most commonly when a failure mechanism (Chapter 9) commences that may lead, or is leading, or has led to breach of a flood defence.

When planning for a flood event, the first step is to review existing emergency action plans to ensure that they are up to date along with recent inspections/risk assessment documentation. Emergency action plans should give a clear and effective structure for handling and managing an emergency. These plans should include:

- Rosters of personnel ready to provide technical and/or direct assistance during a flood response.
- Contact lists of emergency management entities for quick reference; list of emergency contracts that can be used during a flood response or for rehabilitation after a flood.
- Inventory, maintenance and augmentation of sandbags and other special purpose flood response materials or equipment.

At a minimum, the plans should have 3 basic priorities:

1. Executing the protection of life and property during a flood.
2. Means to effectively communicate hazardous conditions to public and involved agencies.
3. Restoring normal operations after the flood.

The plans should be created by senior flood defence personnel with input from local emergency responders and other community members who maintain responsibilities during an emergency and actively coordinated with the appropriate emergency management organizations. The plans should cover:

- Activation of emergency action plan:
  - Designate the authority to activate the Emergency Action Plan.
  - Clearly identify and describe specific conditions that should lead to the plan activation.
  - Confirm the local agency that will take the lead in responding to the flood, typically the agency preparing the plan.
- Steps and actions that need to be taken immediately prior to an emergency:
  - Describe how conditions will be identified then reported.
  - Identify the location of an Emergency Operations Centre (EOC) and set it up.

An Emergency Action Plan needs to be reviewed periodically, especially after it has been activated or after events that could potentially trigger its use. Lessons learned from activation can be important elements for improving the next version of the plan.

12.3 Resources

Resources includes everything required (Figure 12.4) to implement an effective response during an emergency. Resources therefore include:

- The materials/supplies and equipment for the emergency measures themselves (see Section 12.3.1 and details in Chapters 10 and 11).
- Work Force trained personnel and volunteers (12.3.2).
- Equipment and supporting facilities required to support and deliver the emergency response, including:
  - Equipment for communications (link to chapter 7) (see 12.3.3).
  - Equipment for transportation by water or land (see 12.3.4, see also chapters 8, 10 and 11).
  - Storage facilities for materials and equipment (see Section 12.3.5).

- Supporting tools and equipment (12.3.6 see also chapters 8, 10 and 11).
- Equipment for Health, Safety and Wellbeing to ensure all work is carried out safely (link to Chapter 13).
- Shelter and support for personnel (Section 12.3.7).

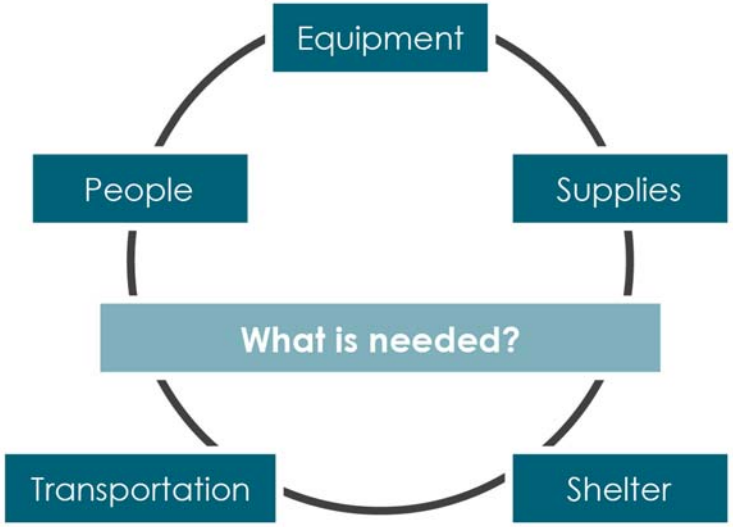

Figure 12.4: Resources required for emergency management of flood defences

In the following subsections, each of these will be addressed in more detail.

12.3.1 Emergency measures – materials and equipment

Emergency measures include all those mentioned in Chapter 10 (raising defence crest, reducing load, strengthening the defence, erosion protection, emergency embankments and breach closure). The main types of materials and equipment that will be required for these measures include the following:

- **Sandbags, big bags, location independent barriers and membranes,** all as described in detail in Chapters 10 and 11.

Providing training for emergency operations, Skagit County, WA

In November 2021, Seattle District Emergency Operations Center flood response team provided technical assistance (see e.g. Figure 12.5) to Skagit County representatives at Burlington, WA. The training was to help the county provide emergency materials to the community in preparation for the atmospheric river event and to mitigate flooding in the region.

Figure 12.5: Using a sandbag filling machine during training (courtesy: Seattle District Skagit Flood Team.)

- **Building materials** such as timber, plywood, nails, and screws are needed for emergency repairs, reconstruction, and rebuilding

damaged structures. These materials are essential for repairing roofs, walls, and other structural elements.

- **Portable bridges or boardwalks** may be required to restore access to areas that have been cut off or damaged by floodwaters. They provide temporary solutions for transportation across flooded or compromised infrastructure.
- **Construction and repair tools.** Various tools are needed for debris removal, construction, and repairs. These may include hammers, saws, drills, shovels, wrenches, crowbars, and other hand tools, as well as power tools like chainsaws, generators, and pumps.
- **Construction equipment.** Earth moving equipment and heavy lifting equipment can be used to raise crests, place stability berms and move large sandbags into place. This equipment can also be used to assist placement of slope armouring to arrest erosion that may be experienced during high water.
- **Temporary fencing materials** are useful for establishing restricted areas, controlling access, and delineating safe zones during the flood response. They help ensure public safety and protect critical infrastructure.
- **Personal Protective Equipment (PPE) and first aid supplies** are essential to ensure the safety of responders and affected individuals. Full details on this are given in Chapter 13.

For an effective response, the key requirements for the above materials and equipment must be understood clearly. These include:

- **Quantity**. How much materials and equipment of different types and sizes are likely to be needed can be assessed by:
  - Carrying out stress tests using various what-if scenarios (including for different severities of event).
  - Benchmarking against the types and quantities held by neighbouring flood defence managers or partner organisations. Benchmarking also provides information on what might be used or borrowed from these organisations during an emergency.

  Ideally materials and equipment will be reusable. However, depending on the situation some materials (e.g. sandbags) will only be useable a few times. If this is the case, an inventory should be kept and degraded materials replaced in a timely fashion.
- **Location.** Where the materials and equipment are likely to be needed. GIS can be a valuable tool to quantify travel times from storage facilities and available quantities in relation to key risk areas.
- **The level of maintenance** needed for the intervention. Ideally interventions would be low maintenance, although this depends on cost. If maintenance is needed, ensure that requirements for this are in place.
- **Storage of materials and equipment:**
  - Storage should be at different locations organised to minimise travel time in the event of an emergency.
  - Storage conditions (e.g. temperature, moisture) should be appropriate for the storage location (see also Section 12.3.5).

12.3.2 Work force

During a flood response, various types of people and organizations are typically involved to ensure effective emergency management. Such personnel include emergency management personnel, first responders, local government officials, public health professionals, infrastructure and utility workers, and engineers and technical experts. Enough trained personnel are needed to carry out various tasks, such as monitoring the flood defence, conducting patrols, evacuating residents, and operating heavy equipment.

Volunteers (see Figure 12.6), both individual volunteers and established volunteer groups, prior, during and after an emergency, can save lives and improve the speed with which a community recovers. Flood defence emergency managers should know how to effectively secure, develop and manage volunteers, including training them for specific flood response tasks.

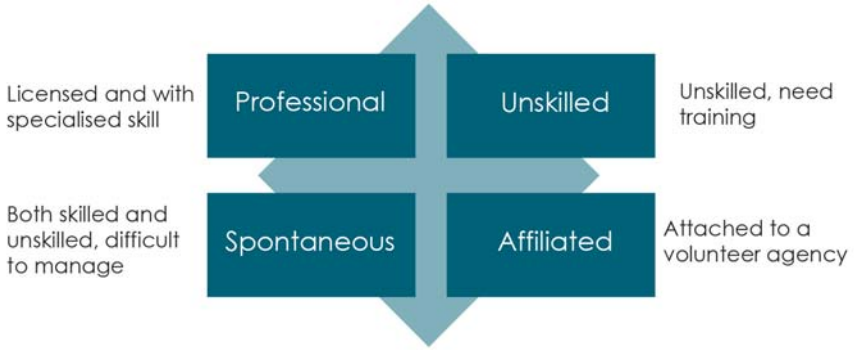

Figure 12.6: Types of volunteers that may work together in emergency management

12.3.3 Communications equipment

Effective communication is crucial during flood response at a flood defence. It ensures that all personnel are informed, coordinated, and working towards a common goal. The needs and requirements for communication are described in detail in Chapter 7 and not repeated here.

The communications plan for an emergency should include an agreed approach to the following:

- **Pre-established communication networks:** Prior to a flood event, emergency response agencies should establish prearranged communication networks and protocols. This includes predetermined radio frequencies, call signs, and communication procedures. Incident Action Plans (which outline the objectives, strategies, and tactics for responding to an emergency) should include communication protocols and establish designated channels for different operational functions. By having these systems in place, responders can communicate effectively without confusion or interference.
- **Interoperable communication systems:** Interoperability is crucial for effective communication between different agencies and jurisdictions involved in a flood response. Emergency responders should use interoperable communication systems that allow them to communicate across different radio frequencies, platforms, and technologies. This ensures seamless information sharing and collaboration among multiple response entities.
- **Briefings and meetings:** Regular briefings and meetings should be held to update emergency responders on the current situation, operational priorities, and safety considerations. These gatherings provide an opportunity for face-to-face communication, clarification of roles, and sharing of important information among responders.
- **Liaison officers:** Liaison officers should act as points of contact between different responding agencies or jurisdictions. They should facilitate communication, coordinate resources, and ensure smooth information flow between the various entities involved in the flood response.

Once an emergency is underway, should use the pre-established communication channels to ensure effective coordination and information sharing. Some common ways emergency responders may communicate during a flood response include:

- **Emergency Operations Centres (EOCs):** EOCs, or mobile command centres serve as communication hubs during a flood response. These vehicles are equipped with advanced communication technologies, including satellite communications, radio systems, video conferencing capabilities, and computer networks. They provide a central location for incident command staff to coordinate operations and communicate with field responders.
- **Two-way radios:** Two-way radios or walkie-talkies are widely used by emergency responders on the ground. They allow for quick and direct communication among responders between pairs of handheld devices using the same frequency within a designated radio network. Within a certain distance, they enable real-time updates, coordination of activities, and relay of critical information.

Although an older technology, it is still very convenient for emergency management. Citizen Band radio with reliable information is similar although more complex than a regular two-way radio as it contains more functionality.

- **Mobile telephones** play a vital role in communication during a flood response. The mobile phone may be either a conventional cellular phone or an ultra-portable satellite phone connecting to telephone networks via orbiting satellites. (Satellite phones are more expensive but more reliable than cellular phones with good connections from anywhere in the world.) Emergency responders may use such phones to make voice calls, send text messages, and share important updates with each other and their command centres, including:
  - Sending notifications via email or text messaging as an effective way to alert large numbers of people.
  - Using mobile apps and messaging platforms for group communications, sharing multimedia content and obtaining emergency checklists and weather alerts (see e.g. the FEMA app in United States or App2c in Europe used for flood defence inspections described in Chapter 8).
  - Use of different social media platforms.

Individual team members should be communications-equipped to maintain a connection with stakeholders, first responders and more generally the outside world in a flood scenario. It is recommended that a variety of communications services (cellular phone, satellite phone, walkie-talkie) are available to them, since there is not guarantee that a particular service will be operational during an emergency. When all modern communication services fail, emergency personnel can also adopt old techniques of communication like the use of loudspeakers on the field or on vehicle. In all situations, as explained in Chapter 8, the team member should try not to be isolated or lost and to remain together in his group.

When using a mobile phone, team members should limit non-emergency phone calls by:

- Restricting the number of phone calls and keeping all phone calls brief.
- Using emails or SMS (short messaging service) messages, as generally emails and text messages will be received when a phone call may not, due to the massive increase of users during an emergency.

As indicated in Chapter 7, information can also be transmitted in a timely manner to members of the public via variable message signs, using social media. A comprehensive and coordinated social media notification strategy should be employed during a disaster, in addition to more traditional methods.

12.3.4 Transportation by water and land

Navigation

When moving around in inundated areas it is important to know:

1. **Where to go**. The location of flood defences that need to be inspected or maintained. Federal Emergency Management Agency (FEMA) (Homeland Security, 2018) recommends that flood defence owners and operators should develop and maintain a list or annotated maps that describe each project feature and areas of concern during a flood event including:
   - Low areas.
   - Areas subject to sand boils.
   - Areas of known seepage.
   - Areas of recent rodent activity.
   - Alternate access points to the flood embankment.
   - Locations of drains that should be checked for closure.
   - Available sources and locations of sandbags, pumps, and other supplies.
2. **Whether it is safe to go there** by a particular route when using land-based vehicles or when walking.

Moving around safely

During flooding, it is important for personnel to know where it may still be safe to walk.

Any place can be represented by a system of coordinates in three dimensions, most commonly to a national grid system or a global system combining latitude, longitude, and altitude relative to mean sea level or to another reference surface. Digital Terrain Models (DTM) – sometimes called Digital Elevation Models (DEM) – are topographic data files or models of land elevation, z_b , that can be manipulated by computer programs.

$$\boldsymbol{d = h - z_b}$$

If the water level *h* is known, it can be combined with the land elevation in DTM to show the water depths, *d*, at any time.

Considering not only water level *h* but also the current velocity *v*, Ramsbottom et al. (2006) developed an empirically based method for evaluating flood hazard rating (HR) for the Department for the Environment, Flood and Rural Affairs (DEFRA) and the UK Environmental Agency (EA).

$$\mathbf{HR} = \boldsymbol{d}(\boldsymbol{v} + \mathbf{0,5}) + \mathbf{DF}$$

where HR is the Flood Hazard Rating, *d* = water depth (m), *v* = velocity of flow (m/s), and DF is a factor which depends on the threat posed by debris, which assumes a value of 0, 0.5 or 1. This flood hazard rating or similar indices (Musolino et al., 2020) can be used to produce maps of flood hazard assessment criteria for pedestrians.

The present location of a person or vehicle can be known using the Global Navigation Satellite System (GNSS). This refers to a constellation of satellites providing signals from space that transmit positioning and timing data to GNSS receivers. GNNS boxes and smartphones offer a precision in latitude and longitude which oscillates, for the best of them, between 5 and 10 meters. They can be used in the field in combination with maps to determine local hazard rating.

Virtual reality or augmented reality tool can also help communities and flood defence stakeholders to visualise flood scenarios in three dimensions and create an immersive picture of serious emergencies (see Figure 12.7). More generally, development of digital twins for flood defences are being developed which integrate three-dimensional model of the flood defence, observations, and numerical models.

Figure 12.7: Augmented reality on a tablet

Transportation

Transporting personnel, materials and equipment during a flood response event can be extremely challenging due to disrupted infrastructure and impassable roads. Nevertheless, with close coordination and collaboration between response agencies, relief organizations, and local authorities, optimal use of available vehicles and streamlined delivery of materials is possible by coordinating transportation routes and by sharing resources and transportation assets.

Strategies that may be used to reduce or make transportation more efficient include:

- **Pre-positioning of supplies:** Whenever possible, supplies should be delivered before the actual flood event begins to overcome transportation challenges during flood response, pre-positioning of essential supplies and equipment in strategic locations prior to the event can be beneficial.

- **Prioritising supplies of materials**. Prioritizing materials based on urgency and necessity ensures that the most critical items are transported first.
- **Utilizing local resources**: Engaging local communities and utilizing their resources, such as boats, vehicles, and manpower, can assist in transporting materials. Local knowledge of alternative routes, hidden waterways, and accessible areas can also be valuable in overcoming transportation obstacles.
- **Temporary access routes:** During a flood response, temporary access routes such as temporary bridges, boardwalks, or elevated platforms can be established to enable the transportation of materials. These routes provide a means to bypass flooded or damaged roads and transport materials directly to affected areas.

Types of transportation that may be considered include:

- **Road vehicles**: A water depth of 0.3m is generally considered the limit for *cars* in a flooded road. This limit can be raised to approximately 1m with the use of a *high-water rescue vehicle* (HWRV). In areas with rugged terrain, *All-Terrain Vehicles* **(**ATVs) or off-road vehicles can be used to transport smaller loads of materials to locations inaccessible by conventional vehicles.
- **Waterborne transportation:** In flood-affected areas where waterways are accessible and safe to navigate, waterborne transportation can be utilised. Boats, barges, or amphibious vehicles can be used to transport materials such as sandbags, construction materials, and relief supplies along rivers, canals, or flooded areas.
- **Helicopter or aircraft delivery:** Helicopters can be employed to transport personnel and materials to areas that cannot be accessed safely by road or water. Sandbags, big bags or other location independent temporary flood defences (see Chapter 11) may be delivered by helicopters. However, the lift capacity of helicopters is generally limited to 10 to 15 tonnes.

Repair of breach of 17th Street Floodwall, New Orleans, LA in 2005

Breach locations can often be difficult to access and have severe working conditions. This was illustrated (Resio et al., 2008) at the breach in the 17th Street floodwall during Hurricane Katrina that impacted New-Orleans (USA) in 2005. Ground access was impossible, and water was moving through the breach at high current velocities. The only possible method for repairing the breach was to drop one-ton heavy sandbags from a helicopter for many days. (Figure 12.8).

Figure 12.8: Helicopter deploying sandbags at the 17th St. Canal following Hurricane Katrina (Resio et al., 2008)

- **Rail access:** Rail access to the flood defence can also efficiently complement road access for supply of materials and equipment. Rail track resilience, however, may be a cause of concern because

floods can wash away ballast, compromise signalling equipment and inundate drainage systems.

- **Multi-mode transportation:** Utilizing a combination of transportation modes can enhance efficiency. For example, materials can be transported by truck to a specific point, and then transferred to boats or other waterborne vessels for transportation to areas inaccessible by road.

12.3.5 Storage of materials

Closely connected to transportation is effective and safe storage of materials. It is crucial to take measures to store materials in a way that protects them from water damage:

- **Planning storage arrangements**
  - **Establish a designated storage area:** Identify a secure location within the emergency response operation area where materials can be stored. This area should be easily accessible to personnel but should also be at a safe distance from floodwaters.
  - **Prioritise essential supplies:** Determine the critical materials and supplies needed for immediate response and recovery efforts. These may include emergency equipment, medical supplies, communication devices, protective gear, and tools necessary for search and rescue operations.
  - **Implement inventory management:** Maintain a detailed inventory system for all stored materials. Use inventory tracking software or manual record-keeping methods to log the items, quantities, and any relevant information. Regularly update the inventory to track usage, restocking needs, and monitor expiration dates of perishable items.
- **Organise appropriate storage conditions:**
  - **Choose low risk storage options**: Evaluate the storage area for potential risks of damage or spoilage to materials, such as leaks, exposure to contaminants, or temperature fluctuations.
    For example, sensitive electronics may require climate-controlled storage to prevent moisture-related issues.
  - **Utilise appropriate containers:** Select sturdy, waterproof containers to protect materials from water damage. Use sealed plastic bins or waterproof bags that can withstand exposure to floodwaters. Consider using color-coded containers or labelling systems to facilitate easy identification and retrieval of specific items.
  - **Store materials and equipment systematically:** Organise materials in a logical and systematic manner (Figure 12.9). Group similar items together and arrange them based on priority or frequency of use. Ensure clear labelling of containers to aid in quick identification during emergency operations.

Figure 12.9: Systematic arrangement of equipment in storage in River Basin Authority Agres-Vedea, Romania (courtesy: Eric Huijskes)

- **Follow safety guidelines:** Adhere to safety protocols and guidelines specific to your organization or agency. This includes following proper handling procedures for hazardous materials, ensuring the storage area is well-lit, and implementing security measures to prevent unauthorised access.
- **Regular inspection and maintenance:** Routinely inspect the storage area and materials for any signs of damage, contamination, or expiration. Replace damaged or compromised containers promptly. Regularly rotate perishable items and restock as needed to maintain an adequate supply of essential materials.

- **Adapt to changing conditions:** During extended flood response operations, the storage needs, and conditions may change. Continuously assess the situation and adjust storage arrangements as required. This may involve relocating the storage area to a safer location or making modifications to accommodate evolving operational requirements.

12.3.6 Other tools and equipment to support emergency response

In addition to the materials and equipment for the emergency intervention itself, an effective response will require other tools and equipment to help address the challenges posed by the flooding and ensure the safety and well-being of affected individuals. The specific equipment needs will vary depending on factors such as the scale of the flood, the geographic location, and the specific requirements identified during the response. However, other equipment needs may include:

- **Evacuation and transportation equipment**
  - Vehicles and trailers.
  - Helicopters or aircraft for aerial rescue or surveying.
  - Temporary bridges.
  - Motorised or non-motorised watercraft for evacuation purposes.
- **Power and lighting equipment**
  - Generators and fuel supply.
  - Portable lights (floodlights, spotlights, lanterns).
  - Extension cords and power distribution units.
  - Batteries and chargers.
- **Monitoring and assessment equipment**
  - Flood gauges.
  - Water level sensors.
  - Weather monitoring stations.
  - Surveying and mapping equipment (GPS devices, drones, laser rangefinders).
  - Inspection cameras
- **Communication systems** - see Section 12.3.3 above and Chapter 7.
- **Personal protective equipment** (PPE) for flood defence emergency personnel. The topic of Health Safety and Welfare (HS&W) is fully discussed in Chapter 13, including requirements for safety equipment.

12.3.7 Shelter and support for personnel

Different strategies may be employed to house and support emergency personnel and volunteers during emergency management. Depending on the situation, these may include:

- **On-site accommodation:** Depending on the scale and duration of the flood response, temporary on-site accommodation may be established near the affected area. This can include setting up camps or base camps that provide basic living facilities for emergency personnel. These accommodations may consist of tents, mobile homes, or prefabricated structures equipped with sleeping quarters, dining areas, restrooms, and basic amenities.

- **Local accommodation:** In situations where the flood response requires a longer-term presence of emergency personnel, local accommodation such as hotels, motels, or guesthouses in nearby unaffected areas can be utilised. This allows emergency responders to have a more comfortable and convenient living environment, with access to amenities and services available in the area.
- **Emergency response centres:** Dedicated emergency response centres can be established as operational hubs during flood response efforts. These centres can serve as a base for emergency personnel to coordinate their activities and provide essential services. They may have built-in accommodations or nearby housing arrangements for the personnel involved in managing the flood response.
- **Existing facilities:** Existing facilities such as government buildings, schools, or community centres can be repurposed to provide temporary housing for emergency personnel. These facilities may be equipped with sleeping quarters, common areas, and basic amenities to meet the immediate needs of responders. The advantage of utilizing existing facilities is that they are usually located in or near the affected area, allowing for quick access to the flood response operations.
- **Support from local communities:** In some cases, local communities may offer temporary housing options for emergency personnel. This can include families volunteering to host responders in their homes or providing access to vacant housing units. Such community support helps create a sense of solidarity and facilitates a more integrated approach to flood response.
- **Logistics and support services:** Along with housing, it is essential to provide necessary logistics and support services for emergency personnel. This includes arrangements for transportation, meals, sanitation facilities, communication equipment (see Section 12.3.3), and access to medical support. These services ensure that responders can carry out their duties effectively and sustainably during the flood response.

In situations where the flood response requires a prolonged effort, emergency personnel may work in rotation shifts. This allows them to return to their homes or designated accommodations periodically to rest and recharge. By implementing rotation shifts, the need for continuous on-site housing is reduced, and personnel can maintain their well-being while effectively managing the response efforts.

In addition, while housing emergency personnel, safety and security measures should be in place to protect them from any potential hazards or threats. This includes assessing the structural integrity of accommodations, implementing security protocols, and providing necessary equipment for personal safety and protection.

12.4 Balancing resource needs with availability

Effective flood response is a dynamic interaction (Figure 12.10) between the needs of an effective and efficient response and the availability of resources: personnel, materials, and equipment. The objective of planning and preparedness is to identify all likely needs and match them with the available resources. This will enable stakeholders to develop comprehensive and realistic response plans while also identifying and addressing any resource gaps that may exist.

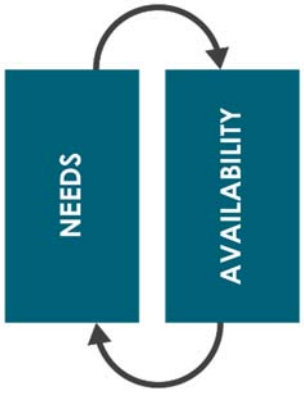

Figure 12.10: Constant dynamic interaction between needs and availability

The matching of resources to needs involves both analysis and action

- **Analysis and preparation**
  - **Needs assessment:** This assessment focuses on determining the resources, capacities, and capabilities required to effectively respond to a flood event. See for example Table 12.1.
  - **Resource identification:** This involves evaluating existing capabilities, stockpiles, funding sources, and available infrastructure that can be utilised during flood response.
  - **Resource gap analysis:** This analysis helps determine the deficit between the requirements and the current availability. It highlights areas where additional resources need to be procured, strengthened, or mobilised to meet the identified needs effectively.
  - **Prioritization and risk management:** This helps ensure that resources are allocated where they are most needed and that the highest-priority needs are addressed first.
  - **Training and capacity building:** In the preparedness phase, efforts are made to enhance the capacity and skills of personnel involved in flood response. This includes training in emergency management, first aid, search-and-rescue techniques, and other relevant areas.
- **Action**
  - **Resource mobilization:** This may involve seeking external support, requesting assistance from regional or international organizations, activating mutual aid agreements, or allocating funds from contingency budgets.
  - **Collaboration and partnerships:** Collaboration between different stakeholders plays a crucial role in meeting the identified needs. Government agencies, relief organizations, community groups, and private sector entities should work together to pool their resources, share expertise, and coordinate efforts.
  - **Continual assessment and adaptation:** This requires continual assessment and adaptation to account for changing circumstances, emerging risks, and updated resource availability. Regular monitoring, evaluation, and feedback mechanisms help refine preparedness plans and improve response capabilities over time.

A flood defence operator should have a thorough understanding of all the resources, personnel, equipment, and materials that may become involved in a flood response – an identified need. Once the need is identified, availability should be checked and ensured.

Tables such as the sample shown as Table 12.1 may be used to identify the needs of a flood response, determine their availability, and recommend a corrective action to ensure availability.

Table 12.1: Sample table of needs, availability, and action to secure resource

Type of Need	Qty	Description	Available?	Corrective Action	Timeline
Personnel					
Flood defence patrol	30	Personnel to conduct flood defence patrol	☐ Yes ☐ No ☐ Partially	Train flood defence patrol personnel	By EOY (end of year)
Materials					
Sandbags	1000	Bags needed to secure areas subject to flooding	☐ Yes ☐ No ☐ Partially	Contact other agencies for inventory	By EOY
Equipment					
Sandbag machine	2	Needed to fill bags on site during flood event	☐ Yes ☐ No ☐ Partially	Secure assistance from agency that can lend machine	Immediate
Other Resources					
Gloves	100	To protect personnel from the elements	☐ Yes ☐ No ☐ Partially	Find vendor and secure inventory	

Logistics in England, UK:

The UK Environment Agency has a close working arrangement with an on-call Logistics Supplier who can deliver pumps, barriers, and other temporary flood defence equipment to anywhere in England within 11 hours. The equipment is stored and maintained in fully serviceable condition at several secure depots nationwide. Each pump and barrier stillage are fitted with a tracking device and a real-time reporting system enables direct monitoring of equipment. Figure 12.11 below shows a summary report of temporary barrier allocation and illustrates the range of information available from the tracking / reporting system.

Any Environment Agency area requiring mobile pumps or barriers will have ready-made Deployment Plans which will detail the assets needed and useful site information including known utilities, access issues, required road closures etc. These plans have been developed to comply with the Construction Design & Management Regulations 2015 (CDM 2015) and are independently verified by specialist CDM Advisors. The Area teams raise requests for the assets (and any additional resources) needed using the on-line Mutual Aid Tool and these are then despatched to the deployment sites in the correct order to carry out an efficient deployment. Audits are carried out at each storage location on a regular basis to ensure all assets are correctly packed, clean, correctly tagged, and ready for deployment.

The Environment Agency is investing in improved technology to enable the tracking software to also report on pump fuel status and to switch the pumps on and off remotely. This saves on unnecessary travel to refuel pumps that may still have several days' supply left in their fuel tanks and allows for more efficient operation.

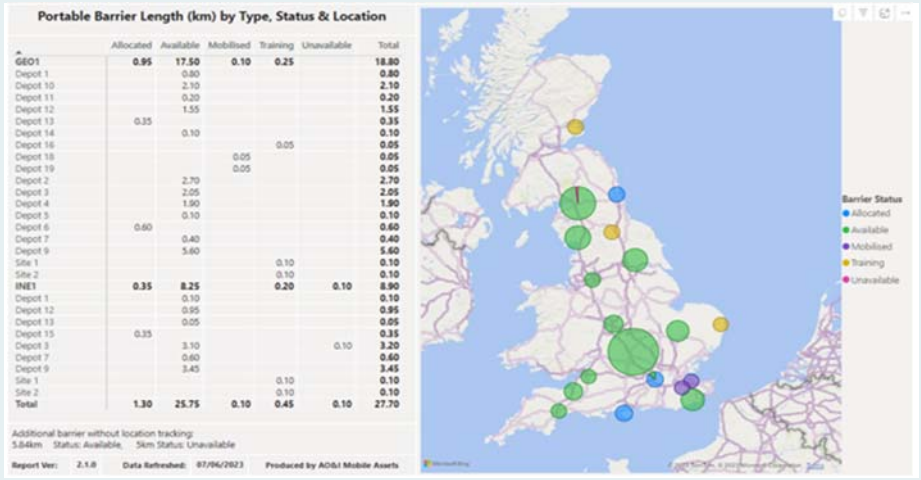

Figure 12.11: Illustrative UK Environment Agency tracking report for temporary barriers

12.5 Transportation and access logistics

Travelling during floods is dangerous. Even just walking a short distance may cause an injury, an attack of a dangerous animal and in waters with bacterial and chemical pollutants serious illnesses may be contracted. When floods occur, there is a risk that you drive a car into a hole, a deeper area, or get washed off the road with strong currents.

Constant evaluation of hydraulics is required during an emergency management operation. For example, if an emergency management team wearing life jackets starts to walk and ends up floating, a transition to a boat-based operation is clearly necessary.

12.5.1 Boating in flood waters

While boating is a convenient means of transport across flooded areas, it can also turn out to be dangerous. Dangers in floodwaters include,

- **Debris** such as sharp metal debris, large branches or building materials float in the water. These floating debris are sometimes hidden just under the water surface and unseen since floodwaters are often muddy. These dangerous debris may clog the raw water intake of an engine and cause it to overheat.
- **Poor manoeuvrability**. of the boats is difficult with very strong and strange currents which require a very good pilot experience. Even in river channels navigation may be dangerous as beacons and buoys can be moved or damaged.
- **Electrocution**. Electric poles fall into the water with their lines and electrical equipment in the water and cause an electric shock.
- **Chemical damage**. Dangerous chemicals could harm boat's paint finish and the boat may need to be washed down thoroughly after navigating floodwaters.
- **Hypothermia** Since flooding often occurs in winter, cold water can cause thermal shock and risk of hypothermia.

Strict protocols must therefore be followed when boating (see Figure 12.12), which address these dangers.

Figure 12.12: Motorised boat with staff carrying life jackets (source: U.S. Army Corps of Engineers)

These protocols will typically include:

- Not less than two people on the boat.
- Boat equipment to include:
  - Navigation lights.
  - Navigation system. The Global Navigation Satellite System (GNNS) that provides absolute positioning is generally used now also for boating.
  - Motor/propellor adapted to the water conditions.
  - AIS transponder (to allow transmission of the boat's identity, position, etc. to all other vessels within range and receipt of data from those vessels).
  - Ropes to tie up the boat or to rescue someone who has fallen into the water.
- Appropriate equipment personal protective equipment for the crew including life jacket.
- Appropriate communication equipment (see Section 12.3.3).

Boating in river channels during floods

In inland waterways, the maximum water level on which navigation can take place safely and without damaging the riverbanks by ship wash should be determined and enforced. Techniques that can improve safety and avoid damage include:

- Use of a high-water vehicle as a boat launch platform, which prevents the boat crew from having to walk the boat through shallow water.
- Appropriate mooring in times of flooding to avoid boats hitting the berth, being damaged or becoming stuck when the water level falls (Chauvin, 2022). This includes regular adjustment of the length and tension of mooring lines as the flood rises and falls.
- Choosing the place to dock carefully. A parking area for example inside of a curve should be preferred because the current is slower, and a submerged dock should be avoided.

Adapted boating in urban areas and shallow waters

Local rapid water flows can be dangerous in urban areas, causing boats to hit fences, vehicles, or houses. When navigating above a submerged road, the water will typically be deeper along the side and shallower in the middle because of the crest of the roads. Boats must therefore be adapted to these conditions with the appropriate propeller and motor and a hard bottom to avoid holes being made by flood debris. Emergency rafts, inflatable boats and paddle boats are particularly adapted for this purpose. The selected boats must also be narrow enough to pass through restricted areas but have enough capacity to transport staff and materials.

Boats are operated at slower speeds when navigating in shallow waters to avoid creating that might damage a flood embankment or other property. Current velocity also can change during the operation, which may require prompt adjustments to the thrust of the engine. Paddle skills for the crew are sometimes necessary in addition to use of the boat engine.

12.5.2 Driving cars

If flooding is likely to occur, it is generally best to avoid driving in floodwaters, even with a four-wheel vehicle, because your vehicle can be quickly swept away with strong currents. Even without any currents, a typical car starts to float as soon as the water depth reaches 0.3m. Experimental studies have focused on the stability of parked vehicles and have provided analysis to determine the depth and velocity required for a vehicle to float or slide. A road is assumed to be impassable only when the limit of thirty centimetres is reached. But loss of control and possible stalling of the engine can occur when most passenger vehicles are only in 0.15m water.

Determining maximum acceptable vehicle speed

Pregnolato et al. (2017) propose the following equation for the maximum acceptable vehicle speed *V* that ensures a safe control of the car given the water depth *d* is:

$$V = 0.0009\,d^2 - 0.5529\,d + 86.9448$$

where the vehicle speed *V* is given in km/h and the water depth *d* in mm. Use of the equation indicates that safe control is only possible when the water depth is less than 0.3m (see e.g. Figure 12.13)

Figure 12.13: Water depth inferred from the proportion of wheel that is submerged from (Pregnolato et al., 2017)

If use of a vehicle is necessary for emergency reasons, driving should only be attempted when the water covering a road is still and shallow. Use a high wheelbase four-wheel drive vehicle in good condition that can safely drive through a relatively high level of flood water. In extreme events, only trucks should be used.

When driving, road safety and road closure signs should always be obeyed. The vehicle must also be driven carefully and constant checks made for changes in water depth and speed. (Attempting to cross or drive along a river is particularly dangerous as the power of the flow can often surprise the driver.) A slow and steady driving technique should be adopted to avoid creating a wake, having water sucked into brakes or engine or having the tyres losing traction. The driver should also look out for possible landslides that frequently occur during floods. When flood is accompanied by heavy rains, headlights and fog lights should be used and extra space should be left between the vehicle and the one in front.

Even after flood waters have subsided, care is still necessary when driving because the road may be slippery and there may be debris, potholes, erosion, and other damage to the road.

12.5.3 Access to flood embankments

Vehicle access onto flood embankments is generally possible via ramps located on the landside slope and/or the waterside slope of the embankment. On the landside they make a connection between the access roads leading to a flood defence and the roadway on the crown of the flood embankment. However, for flood embankments of lesser importance, access roads, ramps, and a crown roadway may be absent. Sometimes, even pedestrian access can be restricted by adjoining private land.

12.5.4 Accessibility of the road network

An important part of preparedness (see Chapter 3) is to ensure the adequacy of road infrastructure in the event of flooding. Some low-lying roads and bridges are ill-adapted to floods because they may be unsuitable as escape routes and, on the other hand, may cause additional flooding by trapping debris and restricting water flows. Short term solutions to the flooding of roads and bridges include:

- Use of pumps to remove excess water
- Temporary bridges, capable of carrying automobiles, which can be deployed rapidly.

Longer term solutions include:

- **Elevated roads** which rise above the surrounding ground along their entire length and are usually also built for reasons other than flood protection such as optimizing traffic flow or minimizing environmental impacts.

  At Miami Beach FL, authorities have raised roads in many areas by two feet to combat tidal flooding and help to drain surface water

- **Floating roads** are both a temporary and permanent solution. Built on the water, they are placed on floating pontoons, so that they can move according to the change of the water level. Able to be quickly assembled and moved, and taking up less space than traditional solutions, floating roads are more flexible than bridges and can also be used to divert traffic in the event of road construction.

  The Afsluitdijk is a 30-kilometer-long flood embankment and causeway crossing a large bay in the northwest of the Netherlands. The embankment is equipped with sluices and navigation locks to allow the evacuation of water between the Ijsselmeer and the sea and to make the waterway navigable.

12.6 Real time decision-making

Flood defence emergency managers must be trained and able to make rapid decisions in real time. They should however understand that any decisions they make:

- May constrain their options when making subsequent decisions.
- May improve or worsen the emergency to be managed.

Decisions made in real time to ensure/improve the safety of flood defence personnel and the success of the emergency management operation can be improved by continual situational awareness. Situational awareness refers to the ability to understand and anticipate potential hazards and risks in the environment, and to make informed decisions based on that understanding.

Dynamic decision-making (Brehmer, 1992)

According to Brehmer (1992), a dynamic decision-making problem has four characteristics (Figure 12.14):

- A series of decisions is required to reach the goal.
- The decisions are not independent; that is, later decisions are constrained by earlier decisions, and in turn, constrain those that come after them.
- The state of the decision problem changes, both autonomously and because of the decision makers' actions.
- The decisions must be made in real time.

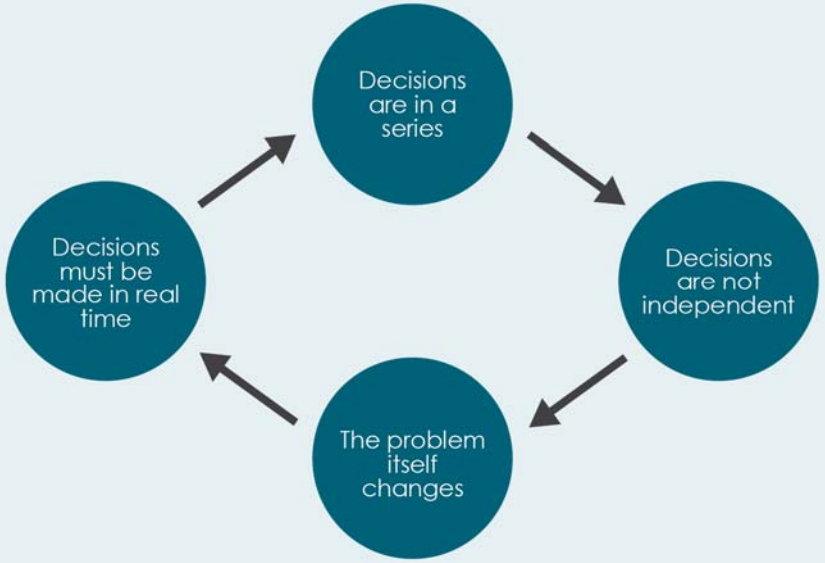

Figure 12.14: Dynamic decision-making characteristics

Situational awareness can be improved by:

- Staying informed.
- Being aware of potential hazards.
- Monitoring and recording changes in flood levels and wave conditions.
- Monitoring and recording changes in the flood defence condition, and any responses implemented.
- Communicating effectively.

Section 12.3 has set out the resources that are typically needed in for managing a flood defence emergency. However, there is a dynamic interaction between emergency response, the actual site conditions and the availability of resources (Figure 12.15). Thus, despite best planning and preparation efforts, the changes in conditions may interrupt or limit the actual availability or usability of materials, resources, or personnel that previously may have been considered secured.

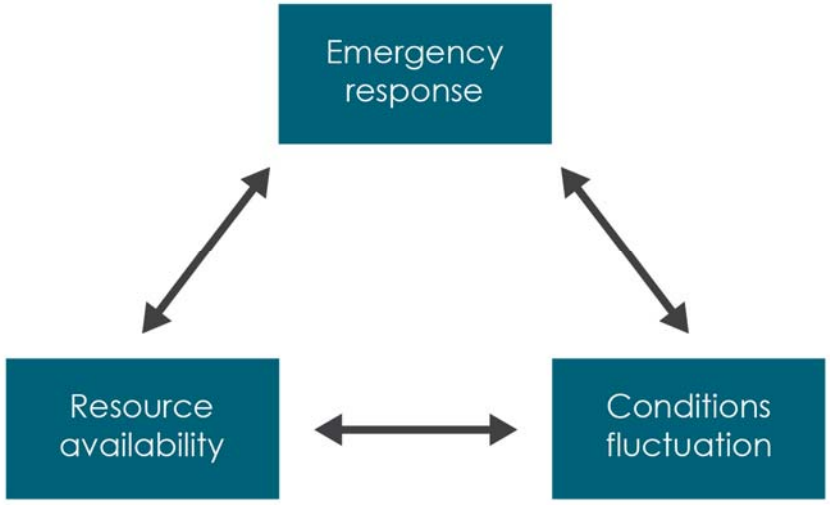

Figure 12.15: Flood response considerations

The types of unexpected changes that may have to be accommodated during the emergency include the following:

- **Environmental conditions**. Temperature, rainfall, wind speed, water levels and wave conditions can change unexpectedly. despite skilled forecasting and constant monitoring of weather forecasts.
- **Resource limitations**. Emergency managers may face unexpected shortages of personnel, equipment, and supplies, especially in large-scale or prolonged flooding events. Limited resources can hamper response capabilities and necessitate prioritization of critical tasks and needs.
- **Communication failures**: Communication systems may be disrupted or overloaded during flood events, making it challenging to coordinate response activities, disseminate information to the public, and communicate with partner agencies and organizations.
- **Health and safety risks**: Floodwaters can pose various health and safety risks, including contamination with sewage, chemicals, and other hazardous substances; the spread of waterborne diseases; and the presence of dangerous wildlife such as snakes or alligators.
- **Logistical challenges**: Coordinating logistics such as transportation, fuel, food, water, and equipment can be complex during flood response operations, particularly in remote or hard-to-reach areas with limited infrastructure and resources.

Even after floodwaters recede, the threat of additional flooding or secondary hazards such as landslides, dam failures, or infrastructure collapse may persist, requiring ongoing monitoring, assessment, and response efforts.

As a result of these potential unexpected changes, dynamic adaptation to the changing circumstances of an emergency is a balancing act that requires the involvement of experienced, flexible flood defence emergency managers. The managers will need to make very rapid decisions and take decisive action to navigate and circumvent rapidly changing conditions on the ground as well as unexpected surprises in personnel, material and/or equipment availability. This means that

designated emergency managers must develop the skills and familiarity to practice dynamic decision making.

12.7 Monitoring and evaluation

Continual monitoring and evaluation of the condition of a flood defence during an emergency should be carried out to ensure that the flood defence is functioning effectively and to identify any areas of concern that need to be addressed. This process should use the assessment and inspection techniques described in Chapter 8 and may require the use of specialised equipment and techniques.

The monitoring and evaluation will help to identify risks and vulnerabilities, and implement timely and targeted response measures to protect lives, property, and critical infrastructure.

Monitoring and evaluating a flood defence as described in Chapter 8 involves ongoing assessment and inspection to ensure its structural integrity and effectiveness in flood control. Here are some of the key elements involved in monitoring and evaluating a flood defence:

- **Regular visual inspections**: Periodic visual inspections of the flood defence structure are essential to identify signs of damage or erosion. These inspections are typically conducted by trained personnel who look for cracks, seepage, animal burrows, vegetation growth, and other potential issues.
- **Site investigations**, which may include:
  - **Detecting seepage and piping**: Engineers may use various techniques to detect seepage and piping within a flood embankment, including the installation of seepage control measures and the use of geophysical methods like electrical resistivity imaging.
  - **Instrumentation**: Flood embankments may be equipped with monitoring instruments, such as piezometers (for measuring water pressure within the embankment), inclinometers (for measuring slope stability), and automated sensors to track water levels and weather conditions. These instruments provide real-time data to detect potential issues.
  - **Geotechnical and geophysical Investigations**: Geotechnical assessments involve testing the soil and foundation of the flood defence to ensure stability. This includes soil sampling, laboratory testing, and analysis to determine the condition of the flood defence's foundation and any potential weaknesses. The geotechnical investigations can be used to calibrate complementary geophysical methods and thus extend local interpretations to the entire structure. (Subsurface geophysical methods assess a physical parameter such as resistivity (or its inverse, the conductivity), seismic wave velocity or the permittivity of embankment bodies. This information provides a representation of the distribution of materials within the structure.)
  - **Hydrological and hydraulic studies**: Engineers perform studies to assess the water flow and hydraulic conditions in the area surrounding the flood defence. This includes analysing hydrological factors such as river flow, as well as storm surge and wave conditions and their impact on the performance of the flood defence.
  - **Environmental monitoring**: Monitoring the environmental conditions in the area surrounding the flood defence is important to understand how it may be affected by changes in water levels or other factors. This includes assessing the impact of flood defences on local ecosystems.
- **Data analysis**: Data collected from monitoring efforts are analysed to identify trends or anomalies that may indicate potential issues or areas requiring attention. Data may include information from aerial and satellite imagery which is especially useful for large-scale flood embankment systems. On a more local scale, drone surveys (photogrammetry, lidar, infrared images) complement aerial or satellite measurements and offer better resolution.

Monitoring data collected during the emergency should be used subsequently in various ways

- **Assessments of defence performance under load**. The performance of the flood defence under extreme loading conditions provides an invaluable guide to inform future flood defence maintenance and improvement efforts.
- **Periodic evaluations**: Periodic comprehensive evaluations, often carried out by independent experts, can provide a thorough assessment of the flood defence's condition, its compliance with design standards, and recommendations for maintenance or improvement.
- **Revisions of emergency response plans.**

12.8 Recovery

The recovery phase of a response to a flood typically involves several, generally sequential, activities (Figure 12.16) aimed at restoring normality and repairing the damage to flood defences caused by the flood.

Figure 12.16: Recovery phase steps

12.8.1 Clearing debris

The first step in the recovery stage is to clear the debris that the flood has deposited on and around the flood defence (Figure 12.17). This may include fallen trees, rocks, and other objects that can impede the flow of water. Floods can deposit a wide range of debris on and around the flood defence, including fallen trees, rocks, sediment, trash, and other objects. Clearing this debris is essential to ensure that the flood defence can function properly and to prevent future damage. It is important to coordinate debris removal with other responders and agencies.

Before clearing the debris, assessments are made of the extent of the damage to the flood defences and the type of debris that needs to be removed. Then, equipment such as excavators, bulldozers, backhoes, and front-end loaders are brought in to remove the debris. Workers may also use chainsaws or other cutting tools to remove fallen trees and other large objects.

Figure 12.17: Debris covered flood embankment after Hurricane Katrina (source: U.S. Fish and Wildlife Service)

12.8.2 Inspection and assessment

After the debris is cleared, the flood defence will be inspected and assessed for damage. This process includes:

- A thorough visual inspection of the flood defence, including its structure, soil, vegetation, and any other components that may have been affected by the flood. This includes assessments of:

- The structural integrity of hard structures and the implications of any cracks identified.
- Any erosion, settlement or slippage of the soil on any flood embankment.
- The condition of the vegetation on a flood embankment.
- Any damage to drainage systems.
- Malfunctioning components that may have contributed to the flooding.

- Other assessment techniques, such as ground-penetrating radar, sonar, or other specialised equipment to assess the condition of the soil or other components of the flood defence. These techniques can help to identify any subsurface damage that may not be visible from the surface.

After the inspection and assessment are complete, the findings are documented in a report that outlines the extent of the damage and recommends a course of action for repair or reconstruction.

12.8.3 Repair and reconstruction

Repair and/or reconstruction of a flood defence should aim to ensure that the flood defence is safe, effective, and resilient towards protecting against future floods. It will likely involve the physical restoration of the flood defence to its pre-flood condition or better. Sustainable and environmentally friendly materials should be used for when possible. A repair process (see e.g. Figure 12.18) may well involve:

1. Measures to stabilise the soil. This may only require grading and contouring to limit surface erosion and promote proper drainage. However, in some cases, stabilisation measures may involve the addition of soil or other materials to reinforce the flood defence, improve its structural stability and resistance to erosion.
2. Repairs or replacements of other components that have been damaged by the flood. This may include:
    - Installation of new drainage systems.
    - Reinforcement of flood walls.
    - Repairs to associated infrastructure impacted by the flood, such as bridges, culverts, or roads.

In some cases, complete reconstruction of the flood defence may be necessary if the damage is too severe to repair.

Figure 12.18: Flood embankment repair in Skagit County, WA, USA (source: U.S. Army Corps of Engineers)

12.8.4 Testing, evaluation and monitoring

Once the flood defence is repaired, it will be tested, evaluated and monitored to ensure that it is stable and secure and can withstand future flood events. This may involve

- **Determination of soil properties** such as shear strength, bearing capacity and permeability. Soil testing may involve both in situ tests and laboratory analysis of soil samples from flood embankments and foundations.
- **Stability analysis**, which analyses the stability of the flood defence structure under a variety of conditions. This analysis is typically performed using specialised software and considers factors such as soil type, slope, and water levels The analysis is used to identify any areas of the flood defence that may still be at risk of failure and to develop strategies to address these risks.
- **Monitoring** is also an important aspect of post-flood flood defence recovery. Monitoring typically involves the use of sensors and other equipment to measure water levels, soil moisture, and other factors that can impact the stability and effectiveness of the flood defence. This data is used to identify any changes in conditions that may require further action to ensure the safety and effectiveness of the flood defence.

12.8.5 Future event planning

Planning for future flood events is the final stage in the recovery process, although future events may well already have influenced the repair and reconstruction efforts. Future planning may involve

- Comprehensive potential hazard analysis, involving a review of historical flood data, as well as an assessment of other factors such as land use, climate change projections, and other environmental factors that may contribute to flood risk.
- Assessment of the threats to the flood defences associated with these hazards (see Chapter 5). This assessment typically includes a detailed analysis of the flood defence structure and its ability to withstand various loading scenarios (see Chapter 9). The results may be used in assessment of the impact of potential flood events on nearby infrastructure and communities.
- Development of strategies to mitigate risks and prepare for future events. These strategies may include additional flood defence reinforcements.
- Ongoing monitoring and maintenance of the flood defence to ensure that it is functioning properly and can handle future flood events. This should include regular inspections and repairs to damaged components, and may involve the use of advanced sensors and monitoring systems to detect any changes in flood defence conditions.
- Updating of emergency response plans.

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CHAPTER 13

Health, safety and wellbeing

Key messages:

- **HS&W needs an appropriate organisational culture**
- **Manage HS&W for a successful response**
- **Monitor and support HS&W during emergencies**

Figure 13.1: Structure of the handbook

Other places to find information on the topics of this chapter

Chapter 2: details on the professional organizations involved in flood response, including contractors and volunteers

Chapter 3: essentials for preparedness, including health, safety and wellbeing considerations in high-risk conditions and the importance of a well-prepared crisis organization

Chapter 4: discussion of hazards faced by response workers during flood incidents, with additional guidance on mutual aid for large-scale events

Chapter 8: instructions on selecting, inspecting, and maintaining personal safety equipment, along with tools specific to flood defence inspection

Chapter 10: techniques for preparing and implementing emergency flood measures, including inspections, repairs, and actions to prevent flood defence failure

Chapter 11: key resources and equipment for flood response, including remote monitoring, water height prediction, and safety protocols for rescue and inspection vessels

Chapter 12: understanding of logistics and implementation and needs in relation to health, safety and wellbeing

Chapter 14: impact of health, safety and wellbeing on reliability

Chapter 15: developing health, safety and wellbeing policies and improving safety, with guidance on integrating health, safety and wellbeing into strategy, cultural awareness training, and post-incident debriefings

Chapter 16: understanding how to justify funding of capacities and capabilities of health, safety and wellbeing that need to be in place

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Note:

The Reader is kindly requested to take note of the Disclaimer on page ii of this handbook.

Chapter title page photograph:

Exercise in The Netherlands – all teams geared to deal with the situation safely (courtesy: Willem Helms)

Key messages:

- **HS&W needs an appropriate organisational culture.** Clear governance and organisation are needed to arrive at a sound approach to health, safety and wellbeing. This includes policies, planning, culture and awareness, targeted at all emergency workers (employed, contractors and volunteers.)
- **Manage HS&W for a successful response**. Health, safety and wellbeing are important preconditions for emergency response. If these are inadequate, not only will this imply potential for injuries or deaths, but any intended response is likely to fail. To put health, safety and welfare principles into practice when working in unfamiliar or hazardous conditions, all personnel should understand how to mitigate or control HS&W risks.
- **Monitor and support HS&W during emergencies**. To ensure a holistic approach, it is also important to monitor, support and evaluate safe and healthy work conditions when a flood emergency occurs.

Previous chapters have mentioned elements or phases of flood defence emergency management that include operational actions. For example:

- Chapter 3 sets out the need for a well-prepared and a well-trained emergency management organisation.
- Chapters 8,10 and 11 describes activities associated with preparing for flood response and in particular what inspections and measures can be undertaken in emergency situations (e.g. inspecting flood defences, undertaking repairs and other response actions to prevent the failure of a flood defence).
- Chapter 12 combines the executing of actions, training and preparation with health and safety by describing how to take care of response workers and organise health and safety in all aspects of their work for all phases of the flood event.

All such operations contain aspects of HS&W. HS&W should be considered at every stage of work in the preparation for, response to and recovery from an emergency. This chapter emphasizes a holistic approach, based on a strong HS&W culture within an organisation, to implementing a robust and embedded HS&W system - not simply by managing it as a parallel process. It explains how to ensure safe and healthy working conditions (as part of overall preparedness – see Chapter 3), given the challenges associated with emergency working, and to reduce the negative impacts on wellbeing during and after the emergency response.

The different sections of the chapter explain the why, what, how and when of HS&W:

- Section 13.1 details the principles and gives insight in to why a HS&W culture is important and, by improving the HS&W of emergency workers, results in more effective emergency response.
- Section 13.2 explains why prevention of HS&W is paramount for flood defence emergency management.
- Section 13.3 explains what the elements of the policy plans are and how this system helps to create a culture of safety.

- Section 13.4 explains what specific types of hazards that may be experienced during a flood defence emergency and how to respond to these.
- Section 13.5 gives examples of how good governance of HS&W can be undertaken and how to analyse risks associated with (field)work, using task risk analysis.
- Section 13.6 advises on how to implement safety of work in unfamiliar or hazardous condition by giving an overview and some best practices of control measures like toolboxes.
- Section 13.7 describes ways to monitor HS&W conditions of workers during a flood defence emergency.
- Section 13.8 explains how to provide aftercare support to emergency workers who have responded to a flood defence emergency.
- Section 13.9 describes how an organisation can learn lessons from an emergency using a debriefing process.

13.1 Principles of health, safety and wellbeing

HS&W is important throughout management of an emergency, including the planning/preparedness, response and recovery phases.

13.1.1 HS&W culture in flood defence management organisations

A flood defence management organisation's HS&W culture may be defined as "the product of individual and group values, attitudes, perceptions, competencies and patterns of behaviour that determine the commitment to, and the style and proficiency of, an organisation's health and safety management" (ACSNI, 1993). The reputation of an organisation can be rapidly and significantly impacted (positively and negatively) by its culture and approach to health, safety and wellbeing.

The health and safety goal for all organisations and workers during a flood defence emergency should be to reduce risk to life for response workers and the public affected by the flood. A thorough and conscious focus on risks within an organisation will set an example for colleagues and other organisations to follow. Building a safety culture begins with fostering awareness and training among flood defence emergency management workers. Furthermore, they will be ambassadors of their organisations, who influence the outside environment, resulting in a broader awareness of risk and a culture of safe working.

The following principles should ideally be built into the HS&W culture:

- Leadership establishing culture. The strategic leadership within an organisation should establish a strong safety culture where HS&W is the first consideration when undertaking any activity and is seen by all emergency workers as a prerequisite consideration for all tasks. Setting a strong organisational culture towards high HS&W standards ensures that risk to emergency workers and stakeholders is minimised.
- Understanding risk in a common way. Risk perception can vary enormously between individuals, there should be a common understanding and assessment of the risks facing flood defence management workers.
- Training and empowering emergency workers. Response workers are of critical importance to successful flood defence emergency management. Response workers should be helped to understand the details of their tasks, have awareness of risks and how to undertake their tasks safely in a hazardous environment. Workers must always feel able to refuse to undertake a task if they consider the task or the conditions they face dangerous. Emergency workers at every level within an organisation should feel empowered to act where they see improvements can be made or standards are not being adhered to.
- Assessing HS&W robustly. Organisations should focus on the importance of undertaking robust health and safety risk assessments for flood defence emergency response activities. This will have a cultural impact throughout the whole organisation and on all people involved in response during a flood defence emergency.

- Working effectively and safely in emergencies. The whole organisation should be prepared to work safely during flood emergencies. Flood defence emergencies by their very nature can occur rapidly and therefore it is advisable to plan safe ways of working during a flood defence emergency. Additionally, flood defence emergencies can be unpredictable, so it is important to be able to plan dynamically, depending upon the changing observations or predictions of the hazards and the dangers of operation.

13.1.2 HS&W of response workers

In the response phase of a flood emergency (see Chapter 4), response workers are exposed to different challenges:

- **Weather and site conditions**. The immediate challenging conditions, for example the adverse weather and/or the social environment of the emergency.
- **Injury, sickness and disease**. Workers have the potential to experience injury or illness as part of carrying out their duties. Workers who become sick, are injured or who contract diseases arising from their work can suffer immensely and this can lead to significant economic costs for organisations and communities. These losses could be due to lost workdays, interrupted production, training and retraining as well as health care expenditure or even compensation and legal action. Employers face early retirement, loss of skilled staff, absenteeism and high insurance premiums.
- **Worry and stress**. Response workers, both in the field and when managing the response in a flood defence emergency room/office, may be subject to high levels of stress or concerns about the potential or actual impact of a natural disaster and about unsafe or unhealthy working conditions. This may reduce their ability to undertake their tasks efficiently and safely. The nature of flood defence emergencies may also expose workers to distressing or disturbing situation, especially where there is loss of life. Mental health pressure can have a long-term impact on individuals and reduce an individual's resilience to respond to subsequent future flood defence emergencies, as well as impacting their day-to-day role.

In general, workers are responsible for taking reasonable care of their own and other people's health and safety and this should be considered in all activities they undertake and in whatever locations they are operating. Given this situation, workers should seek to minimise the impact on their health both during the flood emergency and in the recovery phase by

1. Taking appropriate safety precautions in their work, never risking their lives or the lives of co-workers.
2. Finding ways of reducing any worries and stress associated with working conditions.
3. Ensuring they take plenty of time to recover post incident.

In most countries, employers and employees have legal responsibilities to protect the health and safety of all response workers and their families both during the emergency and into the future (e.g. post-traumatic stress. Response workers typically include not only organisational personnel but also contractors and volunteers. Whilst the legislation is not the same in all countries, the principle of taking responsibility for all emergency workers remains the same. Loss of a response worker, or their serious injury, has a significant impact on colleagues, family and society and can also impact the reputation of the profession and the organisation. Failure to comply with relevant Health and Safety laws could also result in prosecution of the flood defence management organisation.

HS&W of volunteers as emergency workers

It is important to take care of the volunteers that are part of the emergency response, adopting preferably similar safety standards to employed workers or at least minimum safety standards for the relevant country. Since 2001, the UN year of the volunteer, countries all over the world have developed different legislation on:

- The health, safety and wellbeing rights of volunteers in operational conditions.
- Compulsory training and liability of organisations to third parties.

- Aspects of insurance.

The international Federation of Red Cross and Red Crescent state that "in the last decade there has been a trend towards the adoption of legislation on volunteering across jurisdictions. This is usually not regarding a particular sector or type of activity but encompasses different voluntary activities. In some countries however, there is legislation specifically regarding disasters and emergencies, which may include reference to volunteers in these situations". (IFRC, 2011).

Legal HS&W responsibilities in the UK

The UK Health and Safety at Work Act 1974 places a responsibility on both the employee and the employer. It sets out the general duties that

a) employers have towards employees and members of the public

b) employees have to themselves and to each other

c) certain self-employed have towards themselves and others.

These obligations also apply to contractors and sub-contractors

More details on employer and employee responsibilities may be found within the legislation, available at https://www.hse.gov.uk/legislation/HS&Wa.htm.

13.2 Prevention in policy plans and culture

Policy plans for HS&W should clearly describe in outline the goals and responsibilities of the flood defence management organisation for emergency management. The policy plans can describe the tasks and responsibilities of the organisation in emergency situations - often they are more detailed than in national plans and regulations. Should these aims, goals, tasks and responsibilities not be clear in the policy plan, commonly understood principles (e.g. those applicable in the European Union) can still be followed.

Principles of prevention of risks to employees in the EEC Council Directive 89/391:

a. Avoid risks.

b. Evaluate risks which cannot be avoided.

c. Combat the risks at the source.

d. Adapt work to the individual, including the workplace, the choice of work equipment and method, to alleviate monotonous work and work at a predetermined work rate to reduce effect on health.

e. Adapt to technical progress.

f. Replace dangerous by non-dangerous or less dangerous.

g. Develop a coherent overall prevention policy that covers technology, organisation of work, working conditions, social relationships and the influence of factors relating to the working environments.

h. Give collective protective measures priority over individual protective measures.

i. Give appropriate instructions to employees.

The challenge of managing safety during flood conditions

The variable nature of flood defence emergencies makes the creation and implementation of good and consistent policy plans and culture critical to safe response, as is adherence to principles similar to those listed above. Dealing with a flood defence emergency can be compared with other situations such as:

- Offices and industrial buildings which are generally highly controlled fixed working environments, where health and safety can be carefully managed and risks avoided.
- Construction sites in challenging or remote locations, which may require much more ongoing and detailed safety management.

Responding to flood defence emergencies is a mix of these two situations, with:

(a) Work in the incident rooms in an office environment; and

(b) Work in the field on or near to a flood defence in potentially remote locations, a possibly flooded area subject to the influence of severe and variable weather conditions.

Such complexity for the flood defence management organisation, including unavoidable risks in the field, requires a careful and dynamic safety management system and a proactive, informed and focused approach (see general discussion in Section 12.6 on managing dynamic situations.)

In many cases flood emergencies are too big to be dealt with by a single organisation or country. This may result in requests for help from other organisations, volunteer groups, the affected communities and, in some circumstances, requests for international assistance (see also the references to mutual aid in Section 4.2 and to collaboration in Chapter 14). This may change the scope of responsibility for organisations during the flood event – something organisations and multi-agency groups should monitor closely. Ensuring the safety of those involved will require careful planning and coordination including:

- Clear work task instructions.
- Provision of training (if necessary 'just in time' or 'on the job' training).
- Provision of any necessary personal protection equipment (for example waterproof clothing and footwear).
- Provision of equipment for undertaking specific activities such as inspection devices or equipment for recording defects.

13.3 Health, safety and wellbeing as a system

Figure 13.2 shows a framework or system that should be helpful when organising health and safety management. It is based on a typical approach to implement health and safety in organisations, enriched with practices from the flood management and emergency response sector. The goal is to systematically develop a culture of health, safety and wellbeing where measures are embedded.

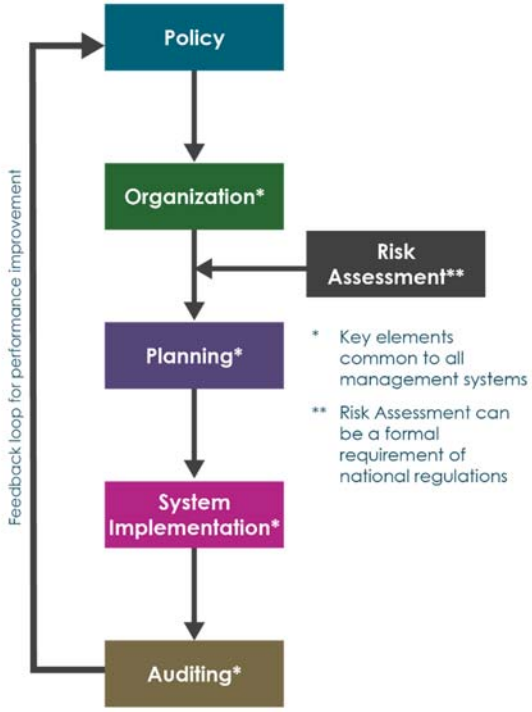

Figure 13.2: Key elements of a health and safety system (after: Griffith & Howard, 2001)

The key elements of a health and safety management system are similar to the general principles of management, with an additional element "The risk assessment" (Griffith & Howard, 2001).

- Implementing a health and safety culture and policy in an organisation needs holistic adoption through the whole organisation (POLICY).
- Managers of an organisation should be committed to health, safety and wellbeing and encourage it, providing resources to implement appropriate frameworks (ORGANISATION).
- Emergency workers should be tasked with.
- Organising procedures (based on RISK ASSESSMENT).
- Instructing (PLANNING).
- Training workers (SYSTEM IMPLEMENTATION).
- Finally, the system should regularly be evaluated (AUDITING) and hence improved (Feedback Loop).

The aim is that it becomes a culture that meets the organisation's philosophy and legislation.

More detail of each component of the HS&W system are provided in Sections 13.3.1 to 13.3.6.

The goal of effective flood management can be reached better when people are better prepared in terms of HS&W for a flood event. The result of a health and safety culture is to keep emergency workers safe and reduce the chance of absences due to sickness, injury, diseases or even death.

A key aspect is establishing the correct balance of risk, so that emergency workers are cautious – they are aware of risks and approaching tasks in an informed and aware manner – rather than being tentative and uncertain with a reduced awareness of the consequences of the risk.

13.3.1 Policy

A policy makes the strategic goals on safety clear for the whole organisation and forms the umbrella for all underlying activities. Organizing a safe working environment starts with the understanding that nearly all organisational activities have an impact on HS&W. At a strategic level these goals can be determined as follows:

- Organise resources (people and budget) for safety management.
- Link HS&W to the existing management systems.
- Explain the organisational strategy and corporate and social responsibilities.
- Record the organisations legal responsibility for HS&W.
- Report on public accountability and state the HS&W policy.
- Continuously promote awareness of HS&W throughout the organisation.
- Provide staff, contractors and volunteers with appropriate training.

By enshrining these goals in policy, the strategic level ensures awareness at the tactical and operational levels.

'Safe and Well Charter' of the Environment Agency, UK

The Environment Agency in England has a 'Safe and Well Charter' that explains the level at which it holds the importance of good health, safety and wellbeing culture and the behaviours it expects to see from all colleagues. See the charter below (Figure 13.3):

Figure 13.3: The Environment Agency's 'Safe and Well Charter'

Five stages of development of a safety culture according to Hudson (2007)

Patrick Hudson's five stages of development of a safety culture (see Figure 13.4) is a frequently used model used to indicate the HS&W maturity of an organisation:

Stage 1: requires an organisation to do what is obligatory to law

Stage 2: the organisation states the importance, but mostly reacts after a flood defence emergency

Stage 3: requires systems and internal safety rules to control risk

Stage 4: asks a proactive approach on safety based on intrinsic motivation for safety and constant improvement

Stage 5: requires fully integrated safety in all organisation processes

When seeking to improve organisational safety, it helps to agree on which of these stages or levels is being targeted.

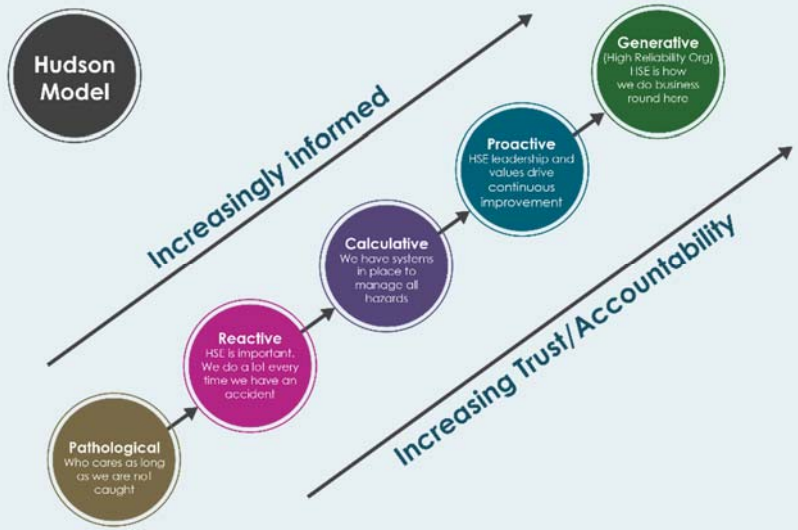

Figure 13.4: Five stages of safety culture according to Hudson (HSE stands for Health Safety and Environment) (after: Bradley, nd)

13.3.2 Organisation

When an organisation is committed to HS&W, the resources to implement it successfully will be well organised and this requires:

- Document or manual describing the organisation of HS&W.
- Designated personnel responsible for health and safety management tasks, including roles in the corporate organisation, in supervision on working sites and in liaison with other organisations and authorities.
- Appropriate levels of detail on safety requirements for different roles in the organisation.
- Production of safe working procedures, handbooks and working instructions.

- The provision of instructions on all procedures related to effective practices in the workspace.
- Planning and organisation of training requirements and inductions or training on site, including (if appropriate) participation of volunteer workers.
- Debriefings, to learn from training and exercises and real incident response.

13.3.3 Risk assessment for HS&W

Risk assessment forms the basis by which an organisation determines the required procedures, detailed instruction and training associated with addressing a risk. Fuller details of the HS&W risk assessment process are given in Section 13.4, but in summary a risk assessment can be done by reviewing working practices using three steps:

1. **Identification of hazards**

This involves systematically identifying potential dangers for response workers. Typical hazards include:

- When working on flood embankments: steep slopes, bumpy or slippery areas, use of vehicles, being part of traffic, working near water, open water, waves and currents or severe weather.
- When working on flood control structures: working from height, working near electric or mechanical parts and working in confined spaces.

2. **Evaluation of the risk**.

Risk is the likelihood that a specified undesired event will occur due to the realization of a hazard. The degree of risk is determined by two factors:

- Severity of harm - the level of harm that a circumstance would create.
- Likelihood of occurrence - the frequency of a hazardous circumstance.

Organisations should identify an appropriate severity and likelihood scale to suit their needs, with clear definitions for each level of the scale.

3. **Development of control measures**.

a. Risk mitigation. This is carried out as part of the preparedness phase and reviewed prior to carrying out emergency interventions on the flood defences. A team (with safety officer, risk assessor and response workers) discusses every identified risk and decides whether it can be dealt with during the flood defence emergency or should be addressed as part of preparedness.

b. Prevention of and protection against risk. It is recommended that this follows the following principles:

- *Avoid risk*. Some risks during emergencies can be avoided by not undertaking specific activities during extreme water levels, currents, sea state or storms. Exceedance of trigger levels (see Section 3.6.6) determines which operations should be commenced or suspended and can be identified in the preparedness phase (see discussion in Chapter 3).
- *Combat risk at the source*. Combating the risks at source can be done by preventive measures on the existing structure or redesigning the flood defence.
- *Control risk*. Controlling the risk may be achieved awareness of the risks and by adoption of appropriate control procedures. Instruction and training of response workers in such procedures should be provided.

Example of risk assessment components for walking inspections

Risk evaluation

During a storm the likelihood of waves overtopping the flood defence that might wash the inspector into the water is (possibly even unacceptably high).

Risk mitigation

As part of preparedness, a risk reduction method that can be used is a flood defence design that limits wave run-up or overtopping, for example using a foreshore berm, shallow slopes or energy absorbing revetment.

Risk avoidance

Monitoring the condition of the flood defence during an emergency (see Section 12.7) could be achieved remotely by cameras and sensors, or prior to the flood or storm peak with an unmanned aerial vehicle (UAV).

Combating risk at source

As part of preparedness, the designer of the flood defence should consider ways of improving the safety of inspection and maintenance during a flood emergency. This might include inspection walkways, stairs on the slopes and berms that help aid safe inspection

Controlling the risk

Risk of inspecting flood defences during flood emergencies may be controlled by:

- Restricting entry to some working areas.
- Working in pairs.
- Appropriate equipment provision, incl. personal protective equipment.

13.3.4 Planning

The systematic planning of risk assessments, instruction and training is fundamental for a HS&W systems management approach. A health and safety plan should comprehensively document all aspects relevant to the HS&W of response workers. It can be separated into sections - one part focusing on the preparation phase and the other part on the response and recovery phases. Table 13.1 gives an example of a health and safety plan and its various topics; the plan has:

- A fixed part that describes policy, system and organisation established in the preparedness phase.
- A dynamic part which focuses on the field or site aspects. This part may be prepared in outline in the preparedness phase but is expanded in detail during the response and recovery phase.

Table 13.1: Example contents of a health and safety plan

Topic	Description
Fixed part describing policy, system and organisation	
Task overview	Nature of the work and tasks during a flood
Health and safety standards	Existing standards the organisation must meet
Management arrangements	Key responsibilities for HS&W
Contractor information	Protocol for work of contractor and other parties working on the flood defence and responsibility for work risks
Selection procedures	Procedures for assessing the competence and resources required for the work activities. This should detail the qualifications which are required for tasks
Communication and cooperation	Lines of communication between the organisation and others for HS&W matters.
Activities risky to health and safety	All hazards and mitigations for each hazardous activity, including specific safe working instructions.
Accident recording	Requirements for reporting accidents, with formal instructions and timescales
Consultation	Procedure for workers to raise health and safety concerns with supervisors
Filing	Documentation and storage of information
Monitoring	Method and procedure for inspection of safe working and health and the way audits are undertaken.
Review	Reporting of earlier accidents and incidents in health and safety that took place and the changes that were made as a result to the Health and Safety plan.
Emergency procedures	Emergency actions: how to alarm, what escape routes are possible, where to meet up and how to check on personnel
Dynamic part focusing on field or site aspects	
Welfare facilities	All arrangements and (temporary) facilities for workers (food, rest, sanitation, medical aid)
Training	Training on health and safety: requirements, induction of workers and training schedule.
(Site) rules	Policy and rules for entering the flood defence site, including restrictions for entering and methods of closing an area off and controlling access (see e.g. Figure 13.5)

Figure 13.5: Flood defence area in Nijmegen NL near Waal River closed for public access during an emergency

13.3.5 System implementation

The implementation of a HS&W system for response workers may be managed by a "safe system of work". This system of work should be:

- Conscious of HS&W.
- Based on procedures that are formalised.
- Understood throughout the organisation.
- Practical in application.
- Enforceable.

When implementing a safe system of work, seven key factors should be considered:

1. HS&W management policies

The policies of the organisation should make clear:

- What health and safety training is given.
- What work are people allowed to do in terms of inspection and in emergency response.

Clear guidance should be provided on:

- What finance and resources are available for health and safety measures, training and equipment.
- What remuneration is available for being on call or operating with special duties.
- What arrangements are made for access to health insurance and after care.

2. HS&W risk assessments

The risk assessments focus on hazards for health and dangers of working safely during flood defence emergencies. Situational awareness for the response activities should be assessed resulting in task risk assessments (TRAs) and job safety assessments (JSAs).

3. HS&W method statements

The safety method statement is used mainly for mechanical structures for the safe operation of tasks and undertaking of work, with full awareness of hazards, managed by various control mechanisms. It can be formalized in instruction cards or be digital with checkboxes. The method statement should include:

- Description of the work and required operations and tasks.
- Description of the location.
- Specification who is supervising or managing the structure.
- Specification of the needs (transport, tools, gears and protection equipment) for operation.
- Explanation of the dangers and occupational health implications.
- Specification precautions to minimize risk in operation.

Note: the HS&W instructions for the task should be provided in the briefing document for the activity that is required.

4. HS&W permits to work

Permits to work or authorisations can be required when entering the structure or approaching the flood defence area. Workers may require specific training on sites where the risk is higher. Some specialist activities are only allowed when certified e.g. dive inspections.

5. HS&W instructions (toolbox meetings) and training

Safety instructions help to raise safety awareness. Also, the tactical information and knowledge of previous field visits and difficulties experienced can be shared. Four groups of instructions should be provided before workers commence their response activities in the field:

1) General safety instructions and agreements on behaviour
   - Safety policy and procedures of the organisation.
   - How to communicate and how to use safety method statements.
   - Expected safety performance.
   - Personal responsibility in field work.
   - Penalties and disciplinary issues of breaching procedures.
   - Encouraging support and cooperation.
   - Schedule of the working hours, shift substitution and team grouping.
   - Appointment of group leaders and explanation on decision making power in case of emergency.
2) Specific technical instructions
   - Identified hazards.
   - Specific requirements of the works.
   - Specific safety aspects in execution of the tasks.
   - How to report flood defence emergencies and near-miss flood defence emergencies.
   - Supervision for undertaking tasks.
3) Instructions about the location of the response activities
   - Designated access routes for the work environment.
   - Location and how to get there.
   - Traffic management.
   - Permits to access the work area.
4) Instructions regarding site safety
   - First aid and emergency procedures.
   - Safety supervisors.
   - Welfare facilities.

6. HS&W project administration

HS&W project administration should cover the following aspects:

- Description of all workers and teams involved in the specific work areas, such as:
  - Which emergency response workers are inspecting which specific flood defences?
  - Which emergency response workers are operating in which area?).
- Records of all management procedures and safe working instructions for the response activities.
- Schedules of response worker activities, back-up and working shifts, taking into account appropriate resting time, time required for traveling, administration and recovery from field work.
- Planning and contracting of catering for the workers during the flood event.
- Certification of the training workers have received to ensure safe working.
- The HS&W project documentation should be used to help report on the organisational impact of an emergency, evaluate the work and support decisions made on managing risks.

7. HS&W management audits

The safety management audits should be undertaken within a short period after the flood event. The audits will help to review how the safety management system has been applied, what benefits of the system were apparent, and what procedures can be changed to improve overall safety management.

13.3.6 Auditing

Effective organisations undertake audits and review of their health and safety management system to ensure that their workers are behaving correctly and that the management system is being applied correctly. Audits can be undertaken using either of the following:

- Longitudinal analysis which looks at one topic throughout the organisation. An example of longitudinal analysis is the auditing of communication procedures from start to finish of the flood event to discover if everybody was well informed to take decisions and execute work.
- Cross-sectional analysis of all topics associated with an activity. An example of a cross-sectional approach would be an analysis of the preparation, operation and effective handling of sandbags.

After the audit a review is required to ensure audit recommendations are used to develop better policies and improved effectiveness or to determine necessary actions to meet new performance standards.

Post incident debriefing (discussed in Section 13.8) is important to identify and capture lessons that need to be learnt from a flood defence emergency.

13.4 Flood related hazards

13.4.1 Working in or near water

During or after a flood, there can be emergency tasks that must be undertaken in flooded areas. For example, flood defence inspectors working close to the water or in the flood plain (see Section 8.5.4). Similarly, people undertaking emergency response tasks, and in some cases, volunteers offering help, are likely to underestimate the probability of getting lost. For example, in 2021 more than 15% of the fatalities in the German summer floods were individuals involved in rescue and emergency tasks (Thieken et al., 2023).

It is therefore important to understand when it is safe to work in or near water, how to work safely, what training is required, and how to select, check and maintain appropriate Personal Protective Equipment (PPE). Individuals must follow their own organisation's requirements in terms of safety when working near water and adhere to any guidance or policies. Generally, each team member should wear full PPE, including floatation vests or life jacket, waterproof safety field boots, hard hats or helmet. Extreme caution must be applied to any work close to flood water, regardless of water depth. Flood water can be fast flowing and is rarely clear, meaning that any depth of water could hold potential hidden danger. For example, it is often the case that drain covers have moved, so walking through flood water can expose emergency workers to the risk of sudden and deep immersion.

A more detailed description of how to work safely on foot in an emergency is given in Section 8.5.4.

Working in or near river and tidal currents and in areas of wave action (on or near coastal flood defences) can expose responders to significant risk. This could ultimately result in drowning or being dragged into the water. Keeping a sufficient distance from the water and wearing a life jacket, as well as potentially working on a safety rope can avoid danger or assist rescue when close to or in water. Figure 13.6 shows the danger of different flow speeds and water heights during a flood. The expected water height in a flooded area can be derived from maps as mentioned in Section 12.3.4.

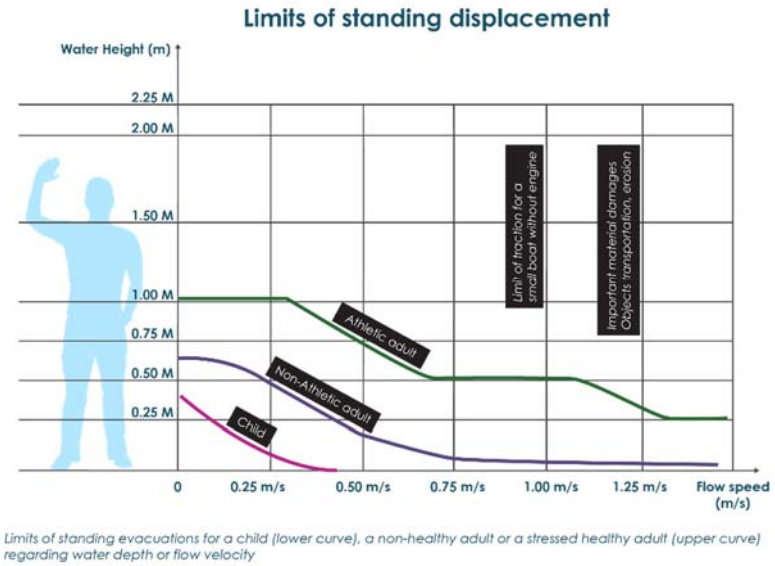

Figure 13.6: Influence of flow speed and depth on safety of work in water

Teams of inspectors patrolling defences may need to walk through water from time to time. If patrols must walk in water, they should walk in still water only and use a stick to inspect the waters that are usually muddy and to check the firmness of the ground ahead that may be not visible. (Figure 13.7) Patrols should carry a safety line to connect team members together, a rescue belt, rescue gear such as a throw-bag. When such rescue gear is used with a twenty-metre-long retrieval rope it may be used to pull a response worker to shore/dry land/or a boat.

Figure 13.7: Inspecting flooded area, using flotation vests and (paddle) sticks to check water depths

Other conditions in which to take care include:

- Dark conditions. Here provide and use high visibility clothing and emergency lighting. A waterproof camera or an underwater surveillance camera may be used to inspect the waters and collect information.
- Contaminated or polluted water. Flood water may be contaminated by pollutants such as foul waste (from the sewage system) or other contaminants. In situations where chemical spills or sewage contamination may be suspected, goggles and protective gloves should be worn in addition to other PPE.

Biohazards in floodwater – CIRIA recommendations in the International Levee Handbook (CIRIA, 2013)

Health hazards from water borne contaminants could be present. These hazards may derive from overflow from sewage treatment plants, or from nearby agricultural or industrial premises, and may include the following:

- Hepatitis – the virus is present in faeces, which can be present in water courses..
- Gastroenteritis – from ingestion of sewage bacteria
- Cholera – an infectious gastroenteritis caused by the bacterium 'vibrio cholerae'.
- Blue green algae – found in freshwater in the summer months, with blooms growing on the surface and which can be toxic.
- Leptospirosis (Weil's Disease) – a bacterial infection caused by rat urine.

Biogenic ground gas may be present in alluvial deposits and at elevated concentrations may represent a risk to emergency workers. Gas monitoring should be carried out at regular intervals during boring and smoking banned at the location of exploration holes.

A summary of appropriate PPE to use in different situations is given in Table 13.2.

Using **boats** or inspection vessels during a flood requires a trained crew, with knowledge about the hazards of mud, debris, currents, waves and navigation. The dangers of boating in floodwater should be properly understood as explained in Section 12.5.1). Using **road vehicles** during a flood can also be dangerous and the good practice set out in Section 12.5.2 should be followed.

Table 13.2: Summary of Personal Protective Equipment to use in different situations

Walking in water	Walking in dark conditions	Walking in a polluted environment	Walking in a team	Walking on slippery ground
Stick Floatation vest Life jacket Waterproof safety field boots	High visibility clothing Emergency light Waterproof camera Underwater surveillance camera	Goggles Work gloves	Safety line Rescue belt Rescue gear Throw-bag	Hard hat Helmet

13.4.2 Flood impact on mental health

Whilst the impact of a natural disaster, such as flooding, can have a significant impact on the public it can also impact response workers. Managing the impact on the mental health of responders throughout a flood defence emergency is vital; failure to do so can impact the resilience of an organisation and compromise its ability to respond to flood defence emergencies and protect the public. The mental health of response workers may be impacted by a wide range of challenges:

- The working conditions experienced due to adverse weather or a busy incident room.
- Stress or anxiety due to the workload or the nature of the incident the individual is dealing with; this can range from fatigue to acute stress.
- The feeling of responsibility to the communities impacted and affected and a sense of failure when communities are flooded, despite all efforts by responders.

- The feeling of responsibility to the communities impacted and affected and a sense of failure when communities are flooded, despite all efforts by responders.
- Negative public opinion about the response by organisations or in extreme cases aggression towards emergency workers involved in the response or recovery phases.
- Fatalities, which can occur on the most severe cases, in which case response workers may need specialist support from healthcare professionals.

In a major incident, lasting days or weeks, it is important that response workers have adequate time to rest during and after a flood defence emergency. Organisations should have adequate systems in place to care for their emergency workers, including ensuring that they are not rostered on too many successive shifts/days and have adequate rest periods built into their working patterns.

Response workers should be given access to wellbeing support throughout and after a flood defence emergency. This can be in the form of either

- formal healthcare support (counselling or workplace occupational health assessments) or
- support from informal 'wellbeing advisors' that individuals response workers can speak to support their wellbeing.

Wellbeing advisors provided by Environment Agency, UK

The Environment Agency (EA) has identified colleagues to act as 'wellbeing advisors' to their staff. These advisors can be approached for informal support. Originally these advisors were co-located in emergency operations centres during emergencies. However, it became apparent that staff who might need support were potentially reluctant to ask for this in the presence of other colleagues. EA wellbeing advisors therefore no longer co-locate in emergency operations centres and staff can make confidential contact with them separately.

Rest days are critical in longer running flood defence emergencies, for example emergency workers should not be typically expected to undertake more than 3-5 shifts on concurrent days before taking a rest day.

It is important that a senior duty officer is responsible for taking an overview of the wellbeing of response workers and that takes action to address any HS&W issues that may become apparent.

13.5 HS&W risk assessment documents

The overall process of risk assessment was described earlier in Section 13.3.3 and covers the process of hazard identification (see previous Section 13.4), risk evaluation and identification of mitigation measures (avoid, combat, control). When viewed in more detail, risk assessment is an activity that contains different levels of operation and different levels of information provision. For example, some supporting documents describe the assessed risk and can be used for assessment purpose (office use and documentation), whereas other documents give direct instruction to the emergency crew on actions to take and what PPE to wear.

This section describes three key documents that support risk assessment: a Task Risk Assessment (TRA), a subsequent Job Safety Analysis (JSA) eventually resulting in a Safety Information Sheet (SIS) and the eventual operationalisation of the preferred approach via a toolbox meeting. The implementation of health, safety and wellbeing in the Emergency Operations Centre is not described, but can use the same considerations as used in such documents (e.g. working hours, shifts patterns, food, mental wellbeing, communication, teamwork).

13.5.1 Task Risk Assessment (TRA)

Organisations can undertake a risk assessment to get an overview on the actual risk situation and actions to control the risk. This can be done using a Task Risk Analysis (TRA) format that can be obtained free online. If it is more appropriate to set up a format specifically for the activity, the main topics to include are:

- Who is at risk of being harmed and how?
- What is already being done to control the risks?
- What further action are required to take to control the risks?
- Who needs to carry out the action?
- When is the action needed to be done?

UK guidance on Task Risk Assessments

The UK Health and Safety Executive has guidance that helps organisations develop an appropriate risk assessment (HSE, 2023). See managing risks and risk assessment at work at https://www.hse.gov.uk/simple-health-safety/risk/

13.5.2 Job Safety Analysis (JSA)

An organisation can analyse each emergency response activity with a more detailed Job Safety Analysis (JSA). This is a safety management tool that identifies unsafe work practices and describes measures to eliminate or control hazards and can be carried out using a Job Safety Analysis (JSA) template such as that shown in Figure 13.8. When completed, such documents should be clear about the conditions in which it is not safe to operate. Individuals and organisations should always put HS&W ahead of 'getting the job done'.

Making difficult decisions about responding to emergencies

In 2018 the UK faced very severe weather conditions during the 'Beast from the East' storm ('Anticyclone Hartmut') which affected transport infrastructure across the country. This impacted the incident response capabilities of organisations who had to make some difficult decisions regarding responding to incident notifications and delayed emergency workers investigating reports.

Job Safety Analysis Worksheet		Date: 01-03-2024
Title of Job/Operation: Levee inspection (while under construction)		Log Number:
Employee Name and Job Title: Reindert Stellingwerff		Analyst/ Date: 28-02-2024
Division/Bureau/Section: Dutch Water Authorities		Approved By/ Date:
Personal Protective Equipment Recommended or Required: hard hat, protective eyewear, steel-toed/shank construction boots, steel-toed/shank chemical resistant boots, ear plugs, protective outerwear, heavy duty gloves and nitrile or latex gloves, dust mask		
Sequence of Basic Job Steps	**Potential Accidents or Hazards**	**Recommended Safe Job Procedures**
Prepare for site visit. Identify site/activity PPE needs; Check contents of PPE equipment bag for complete inventory	N/A	Obtain and review site HASP from contractor; familiarize self w/site prior to visit; know contaminants of concern and properties, locations of suspected contaminant areas. Have proper training completed, and identify appropriate PPE needs. Provide itinerary to supervisor, or periodically check in w/office. MAP LOCATION OF NEAREST EMERGENCY MEDICAL FACILITY
Proceed to vehicle/Travel to and from site	(SB) Moving vehicles on road or in parking areas (SB) Traffic hazards	Be attentive when crossing traffic and walking within parking areas. Map route to site; have area map available; follow defensive driving practices. If using State vehicle: Perform quick inspection for obvious items such as tire inflation, wind shield wipers, sufficient gas to get to destination, observe State guidelines for use of a State vehicle: make certain procedures regarding accidents, injuries, vehicular break downs or roadside emergencies are available in vehicle
Initial site arrival- Assess site conditions Visual inspection of site layout/Walk about site Beware of site security	(E) Weather conditions (SB) Traffic Irritated site owner Dangerous surroundings (BIO) Animals(dogs), snakes, stinging insects	Heat- know signs of heat stroke, have fluids available at site Sun- keep body protected; wear sunscreen when not sampling; wear wide brimmed hat or hard hat. Inclement conditions- seek covered, secure shelter. Extreme cold- layered clothing, gloves, hat, etc. Be alert; attempt to secure area from through traffic. Park with front towards site exit. Be courteous and diplomatic Do not enter site unless accompanied by another inspector or site personnel. Identify areas where biohazards may lurk, plan escape route in advance.

(figure continued on next page)

Oversight during Soil Excavation construction operations	(SB) Heavy equipment operation-front end loader, backhoe, dump trucks, etc. (CW) Dirt, dust, debris	Maintain safe distance from equipment. Wear site/activity appropriate. Do not assist contractor during onsite operations Wear protective clothing and site/activity appropriate PPE, may require dust mask. Identify escape route, position self up wind.
Oversight during Visual inspection of earth works	(FB) Slippery slopes, unevenness of walking path Overexertion	Wear profiled boots, check on slippery or muddy spots, keep distance from edges. While walking on slopes, change direction or pause regularly
Site exit	(CW) Contaminated vehicle	Booties, tyvek, latex gloves should be disposed on-site. Remove boots and soiled clothing for secure storage in trunk; decontaminate as soon as possible. Wash hands promptly. Update exposure log.
Return to office/home	(SB) Traffic hazards	FOLLOW "TRAVEL TO SITE" PROCEDURES.

*Codes for Potential Hazards:

Struck By (SB)		Caught On (CO)		Fall To Below (FB)
Struck Against (SA)		Caught In (CI)		Overexertion
Contacted By (CB)		Caught Between (CBT)		Exposure (E)
Contact With (CW)		Fall - Same Level (FS)		

Figure 13.8: Template of a Job Safety Analysis (JSA)

13.5.3 Safety Information Sheet (SIS)

A Safety Information Sheet (see Figure 13.9) provides instructions to individuals (flood defence inspectors, response workers) about:

- the hazards to be aware of and mitigate
- safety procedures to be followed to help manage the risks
- working equipment that complies with the requirements of the task

It is important that workers follow their organisation's safe systems of work and adhere to all protocols for working safely in the vicinity of a flood defence that has been damaged or breached, especially under severe hydraulic and weather conditions.

Safety information sheet 32

32 Safety guarding flood defences

Explanation/activity	Description
Inspection of flood defences is executed to register the status of the defence. While walking on the crest, slopes and berms, it is checked on cracks and fissures, erosion, wet spots and cavitities.	

Preparatory actions		
Organisation	:	Vallei and Veluwe, regional water authority, NL
Equipment	:	Registration app/ camera/ prone/ PPEs/ reference card/ tapeline/ pickets/ paint sprayer
Crew	:	(Sr.) inspector/ flood defence specialist

Task risk identification (task risk analyses)		
Process activity/task	Hazard/exposure	Control measure
Inspection flood defence	Glance off, fall, stumble	• Wear safety boots with sufficient profile
	Traffic collision	• Wear safety signaling clothing • Place traffic guidance signaling • See TRA working safely in traffic
	Get into water/drowning	• See TRA working safely near watercourses

Figure 13.9: Safety information sheet for flood defence inspection (Regional Water Authority Vallei en Veluwe, 2018)

An example of a safety instruction sheet for setting up a flood barrier using sandbags is given in Figure 13.10. The document describes the risks, measures to prevent injuries and the personal protective equipment required.

FLOOD EMERGENCY HANDBOOK JULY 2020

CHAPTER 3 – SAFETY

Strict adherence to safety procedures are critical to flood fighting operations. Presented below are some important safety tips.

Tip #1	Use proper lifting techniques to avoid injury and fatigue. Lift with your legs and bend at the knees to save your back.
Tip #2	Sandbags are treated to prevent deterioration when stored. Use work gloves and avoid contact with your eyes and mouth.
Tip #3	Stay in eye contact with heavy equipment operator and keep alert for vehicle backup alarms.
Tip #4	Flood waters can be polluted. Use rubber gloves and appropriate clothing if contact with water is unavoidable.
Tip #5	Wear adequate clothing in layers and watertight boots. Reflective material on outer clothing is essential for night work.
Tip #6	Rotate team members frequently to avoid fatigue.

Figure 13.10: Safety procedure for flood fighting with sandbags (USACE, 2020) and sandbagging in Echuca AUS (source: AAP, Brendan McCarthy)

13.6 Implementation of a health and safety culture in the field

Building a culture of health, safety, and wellbeing starts with the preparations for a flood event and continues through to implementation in the field during emergencies. A culture of safety awareness is served by reminders of the commitment to safety everywhere throughout the organisation: in training and exercising, invitations, in plans and procedures, and inclusion in all pictures taken and videos made. On site implementation instructions can be provided via toolbox talks/meetings (Section 13.6.2) and providing field team emergency workers with equipment and PPE (Section 13.6.3) and giving site-specific recommendations on undertaking tasks safely (Sections 13.6.4 and 13.6.5).

Regular training and exercising ahead of managing flood defence emergencies helps to ensure that a strong HS&W culture exits across all roles in an organisation. However, reality will never fully match pre-event training or planning; hence workers must be empowered to re-assess and adjust their approach. Emergency workers should be provided with simple ways in which to check that they are taking the right approach to tasks and have health, safety and wellbeing at the forefront of their thinking. For example, Figure 13.11 provides a simple approach to assessing whether a task can safely be undertaken.

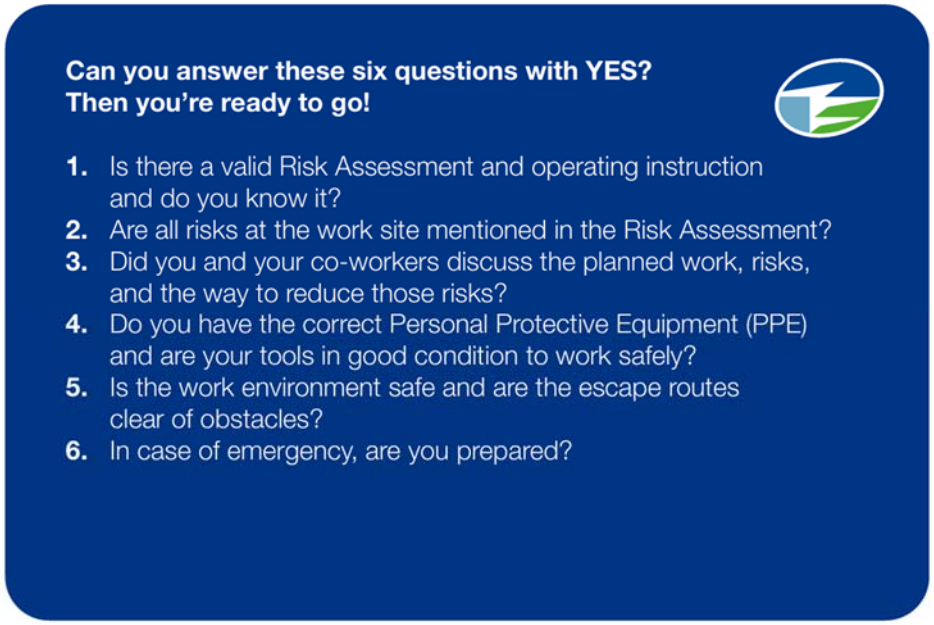

Figure 13.11: Last-minute risk assessment (LMRA) used by emergency workers at Tennet (high voltage grid company) before entering a site (source: Tennet)

Continually staying aware of any changing situations whilst undertaking tasks is also very important and emergency response workers should feel empowered to stop any activities which they deem to be unsafe. All workers must be able to manage risks throughout a flood defence emergency as accidents can still happen despite the best mitigation. Floods, the weather conditions and sometimes the defences are continually changing, so the nature and scale of threats change constantly, during both day and night.

13.6.1Awareness raising and a safety-first attitude

The safety of flood defence inspectors and emergency workers whilst undertaking their work is paramount. Prevention is always the top priority and knowing what to do if something does go wrong is very important and should be discussed before undertaking the task.

Prevention and preparation have five focal points:

1. Prepare to inspect and maintain safely, be aware of access and egress routes (in and out) and routes to leave areas quickly and safely.
2. Prepare for the occurrence of accidents during fieldwork and consider the accessibility of locations for help during night and in bad weather.
3. Comply with the safety requirements when contractors are working on site.
4. Take actions to minimise the risk of accidents involving machines and heavy equipment traffic.
5. Be aware of the surrounding environment and changing conditions.

13.6.2 Undertaking a toolbox meeting/talk

A toolbox meeting or toolbox talk is a short discussion, often given before leaving for the site of the emergency response, intended to make everybody aware of the different safety aspects and dangers at a work site or undertaking a specific activity, aimed at increasing safety in the workplace. Often examples of previous near misses or accidents are used to raise awareness and explain and aid understanding of the safety measure and correct working practices.

The toolbox meeting is held at the start of the work task or operation to remind everyone of the safety arrangements and to refresh the trained safety skills. Toolbox meetings can also be of use to update emergency workers about findings from previous work shifts and to hand over a situational report between colleagues or shifts.

Dehydration toolbox talk
(from safetytoolboxtopics.com)

We've all experienced it at some point when working or playing hard – fatigue sets in, your mouth feels dry, and your legs are heavy and maybe you even get a headache. These are all common signs of dehydration.

When you are working hard, body fluid is lost through sweat. If the fluid lost through sweat is not replaced, dehydration and early fatigue are unavoidable. Losing even 2% of body fluids (less than 1.5 kg in an 80kg person) can impair performance by increasing fatigue and affecting cognitive skills. During the summer heat, it's easy to become dehydrated if you don't drink enough fluids to replace what is lost in sweat.

However, dehydration can easily be prevented:

- **When to drink**: Ensure you drink before you start working, trying to catch-up for lost fluids after a period of time is very difficult. Also, drink before you get thirsty. By the time you're thirsty you're already dehydrated, so it's important to drink at regular intervals – especially when it's hot outside.
- **What to drink**: Water is truly one of the best things to drink. Research also shows that a lightly flavoured beverage with a small amount of sodium encourages people to drink enough to stay hydrated. The combination of flavour and electrolytes in a sports drink provides one of the best options to help you to stay properly hydrated.
- **What not to drink**: During activity, avoid drinks with a high sugar content such as soda and even fruit juices. These are slow to absorb into the body. Also, alcohol and caffeinated beverages should be avoided.

Many people ask how much to drink and that truly depends on your activity level and how much your body is losing fluids. In general, when you are working and sweating, you should drink at least every half-hour. Ensure you are drinking enough to replace your lost fluids. A good rule of thumb from a wise man says, "if you aren't urinating, you're not drinking enough."

13.6.3 Handing out equipment for safely working in flood response

Risks to the health of emergency workers working in remote, flooded areas and in adverse weather conditions can be reduced by taking care of emergency workers welfare, through the provision of good tools and equipment and correct personal protective equipment for all emergency workers. Preparatory measures therefore include ensuring response workers have the correct tools and equipment (see also Chapter 12) and the appropriate personal equipment and PPE (see Table 13.3). The response organisation should take care of these, (check quality and) store them, distribute them or hand them out (in the preparedness phase or before action) and take care afterwards to clean and store them correctly.

Table 13.3: Summary of equipment to hand out for safe working during flood defence emergency management

Equipment	Specification
Tools and gear	• Personal equipment, with instructions about how to inspect and maintain them. See Chapter 8 for specific flood defence inspection tools and 13.4.1 for tools and equipment when working near water • All tools, vehicles and boats (see Section 12.5) should be tested before use • Spare parts should be available
Personal protection equipment	• PPE that matches the size and needs of each person • Training/Instructions in the use of Personal Protective Equipment (PPE) • Spare PPE for any volunteers and non-professionals • Types of PPE are summarised in Table 13.2 above and explained in Section 13.4.
Medical and First Aid Supplies	First aid kits, medical equipment, medicines, bandages, wound dressings, and other medical supplies to provide emergency medical care and address health needs during the response.

13.6.4 Briefing information and instructions that help safely working

Before action takes place, it is important to instruct all response workers on other conditions that influence their health, safety and wellbeing in the field (see Table 13.4 and Figure 13.12).

Table 13.4: Topics for pre-activity instruction

Topic of instruction	Information to share
Site conditions	• Briefing on weather forecast, expected water level and current risk level • Instructing safety awareness during emergency response work • How to make contact in the event of power failure or loss of primary form of communication • Which emergency or inspection field teams have been created and are working on the day • How to work as a team, and how tasks are distributed
Communication	• Contact details in case of emergency (ICE), local support, shelter areas • How to report near misses and (new) hazards • Operational contact to the organisation and to the public • How to finish, debrief and discharge
Permits and authorisation	First explain where field inspectors, other personnel, and vehicles need licences or authorisation to enter the flood area or use private roads/areas to inspect the flood defences. Then make sure all response workers have the following • Personal identification documents and formal mandates for the work. • Permits for executing inspections/maintenance on waterworks and adjacent properties • Approvals to enter restricted (flooded) areas, waterworks and structures Parking charge exemption certificates.
Location	• Location or area of work • Knowledge on how to come to and how to leave the area • Which other nearby field teams are operational and their location or area

Figure 13.12: Briefing and safety instructions before going out in the field

13.6.5 Considerations for working in non-familiar situations

Sometimes response workers are required to work on remote areas, areas unfamiliar to them or in different countries. The response organisation should ensure correct preparation for such a mission. The organisation receiving the visiting specialists must ensure they undertake appropriate familiarisation, supporting them with additional equipment, tools and training if required.

Preparation before departure for the new area may include provision of any of the following:

- Work permits/visas.

- Insurance for travel and health and third-party liability.
- Required vaccinations.
- Awareness and instruction regarding cultural differences (see Chapter 15)

On arrival in the new area the visitors may need to be provided with any of the following:

- Hotels/Housing.
- Transport: car rental/transport (visitors to bring driving licences).
- Local support and In Case of Emergency (ICE) emergency contact details.
- Language/ translation / face-to-face interpreting.

13.7 Monitoring

Organisations have an oversight responsibility for the HS&W of all emergency workers. The workers also have a responsibility for their own health, safety and wellbeing. The following guidelines help frame these responsibilities:

- An environment should be promoted whereby workers can be honest and open about the challenges they face at any stage of an emergency and raise these with managers, receiving support to mitigate these risks.
- Organisations may take a variety of proactive approaches to managing the risk to workers. For example, this can be in the form of identified individuals who are responsible for monitoring risk and addressing the health and safety condition of teams, reporting it and implementing mitigation.
- Organisations should specifically and proactively establish ways of monitoring remote workers. While It is relatively easy to monitor the HS&W of workers when face to face, it is difficult to monitor impacts on the HS&W of remote workers, particularly on their wellbeing, especially when emergency workers may be under acute pressure when responding to an emergency.
- All near-misses experienced should be reported via an organisation's designated method. These should form the basis of toolbox instructions for safe working and inform any additional mitigation required to prevent a recurrence.
- HS&W debriefings should be conducted after emergencies to identify lessons and then undertaking work to embed these in the response to future emergencies. This is further explained earlier in this chapter, see Section 13.3.6.

13.8 Aftercare support

Response workers who have experienced stressful situations during a flood should be offered additional mental health support, for their current and future wellbeing. This should be arranged by the organisation and can include:

- Appointing a qualified mental health provider/professional.
- Providing access to evaluation sessions to ascertain the type of support required.
- Organising individual appreciation and honouring in a manner fitting to the local culture.
- Organising personal aftercare and ongoing financial, medical and emotional support if required.
    - Organisations often have support services that workers can access when in challenging situations. It is important that workers understand how they can access such assistance programmes. Workers should be able to access this support both via their supervisor or directly (in case they should wish to access it confidentially).
    - In terms of emotional support, emergency workers should be encouraged to contact wellbeing advisors (see Section 13.4.2) should they wish to discuss any impacts on their wellbeing as a result of an emergency.
- Providing additional support to workers who, depending upon their involvement and role in a flood defence emergency, may

experience significant longer-term impacts of being involved in an emergency.

13.9 Learning lessons by debriefing

After a flood defence emergency, organisations should undertake a debrief of the flood defence emergency to identify lessons that can be learnt by the organisation. It helps to designate an individual/individuals for this task who can listen well, to analyse issues and develop solutions and if necessary, advise on further support that can be provided to impacted individuals. Debriefing is also discussed in Chapter 15.

Debriefings about HS&W can take the form of hot and cold debriefs.

- A hot debrief should be undertaken at the end of a shift or phase of work to capture any important items, including those that immediately require action or attention.
- A cold debrief should be undertaken sometime after the emergency is over. It should be a more structured and in-depth debrief, to identify as many lessons as possible, which the organisation needs to address.

The flood defence emergency organisation should put in place a process to learn from any lessons identified in debriefings to ensure that any problems do not recur in a future emergency. It is also important to give feedback to those who participated in the debriefing to explain how the lessons identified have been converted into lessons learned. This is usually through altering a working practice or process or by providing additional training to emergency workers.

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NOTE: This chapter may be cited as: Stellingwerff, R. & Thornely, B. (2024) 'Chapter 13: Health, Safety and Wellbeing' In Vonk et al (eds) International Handbook on Emergency Management of Flood Defences. Rijkswaterstaat, Utrecht, and Japan Bosai Platform, Tokyo.

CHAPTER 14

Reliability of emergency measures

Key messages:

- **Emergency measures cannot prevent all failures**
- **Reliability of emergency measures can be estimated**
- **Exercise and train to improve reliability**

Figure14.1: Structure of the handbook

Other places to find information on the topics of this chapter

Chapter 2: high level overview, showing the emergency cycle

Chapter 3: preparedness phase, i.e. one of the quadrants of emergency cycle

Chapter 4: response phase, i.e. the subsequent quadrant of emergency cycle

Chapter 5: relevant flood characteristics that can impact reliability

Chapter 6: an overview of the types of flood defences that are considered

Chapter 7: impact of communication in a reliability analysis

Chapters 8 through 12: details of the process and appraisal of factors that need to be considered to arrive at a reliability analysis

Chapter 13: impact of health, safety and wellbeing on reliability

Chapter 15: impact of capacity building on reliability

Chapter 16: justifying the funds for the needed capacities and capabilities, in particular identification of specific items that need justification

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Note:

The Reader is kindly requested to take note of the Disclaimer on page ii of this handbook.

Chapter title page photograph:

Emergency embankments that were not effective (courtesy: USACE)

Key messages

- **Emergency measures cannot prevent all failures**. Even if a measure has been well prepared, it is important to understand that it may still fail by incorrect design and installation, human error, and operational (structural/hydraulic) failure if the hydraulic loads exceed the available resistance. Thise quality of emergency measures is also constrained by the time available to deliver them and this also affects their reliability.
- **Reliability of emergency measures can be estimated**. The effectiveness of the emergency measure is defined as the extent to which the reliability of the flood defence system is increased (i.e. the probability of failure decreased) by implementation of the applied emergency measure.
- **Exercise and train to improve reliability**. Success factors to improve the reliability of emergency measures include: conducting exercises for simulated high water events, preparation and training in correct installation and operation of emergency measures and ensuring awareness of appropriate organisation and preparation for all aspects of the process

During floods, flood defence management authorities, residents, and the military often collaborate to place sandbags, big bags and other emergency measures, attempting to prevent large breaches in flood defences. This chapter analyses the reliability of emergency measures and describes their effectiveness in preventing breaching of existing flood defences.

The effectiveness of emergency measures strongly relies on the avoidance of human errors and logistical failures and on avoiding the technical failure of the measure itself. To evaluate the effectiveness of emergency measures for flood prevention, this chapter describes a probability-based method that evaluates the effectiveness of emergency measures, from initial detection of the need to install them and through to installation and operation.

In this chapter, emergency measures refer to temporary measures (see Chapter 11) implemented during a flood defence emergency to reinforce, or repair, weak spots in flood defences using various techniques (see Chapters 10 and 11). Weak spots are damaged sections of the flood defence, where a breach can occur during a flood if no measures are taken. The required emergency measure depends on the type of flood defence, the extent of damage and the length over which the flood defence is damaged.

When emergency measures are applied, failure of the flood defence can still occur despite a correctly functioning emergency measure. Using a probabilistic approach, the chapter analyses how emergency measures fail by dividing their operation into three phases: a detection phase, an installation phase and an operation phase. Only when these three phases have been completed successfully will the emergency measure work as intended. The chapter builds on:

- Specific analysis for this topic by Lendering (2018) and others.
- Work on the reliability of earthen flood embankment by Jongejan et al. (2013), Vrijling (2001) and others.

- Work on the reliability of human and organisational systems in flood defences in the context of the closure of complex storm surge barriers (Vrancken et al., 2008).

The chapter focuses on emergency measures which aim to prevent the initiation of breaching of river flood embankments. Emergency measures which aim to prevent breach growth and/or to close breaches are beyond the scope of this chapter. We also focus on the most significant failure modes of flood embankments, namely overflow/overtopping leading to external erosion, backward erosion piping and landslide slope instability.

The chapter is structured as follows.

- Section 14.1 describes the general method for assessing the reliability of emergency measures. Here distinction is made in detection failure, installation failure and operation failure.
- Section 14.2 describes how to include the time factor into the reliability analysis, comparing the time required with the time available – emergency management is always time constrained.
- Section 14.3 includes case studies where the methods are applied.
- Section 14.4 provides recommendations for improvement of the reliability of emergency measures.

14.1 General method

14.1.1 Introduction

Flood embankments surrounding a flood-prone area can be divided into sections that have similar hydraulic conditions and characteristics. The flood embankment sections can be assessed leading to one of two results:

- Safe (meeting the requirements for a maximum failure probability).
- Not safe (not meeting the requirements).

If the flood embankment section does not meet the requirements, it may be reinforced. The result of the assessment of these flood embankment sections is presented in Figure 14.2.

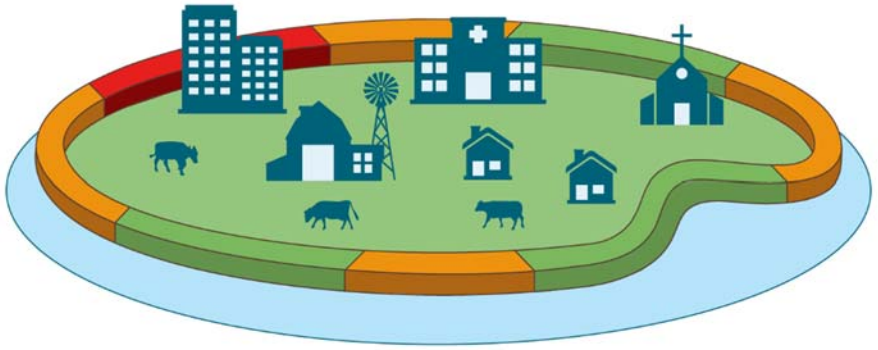

Figure 14.2: Flood probabilities for flood embankment sections are shown in red (high), yellow (medium) and green (low)

A general approach for assessing the reliability of emergency measures was proposed by Lendering (2018) and shown in Figure 14.3. It assumes the occurrence of a flood event, and the implementation of emergency measures to prevent a breach in the flood defence. The first event in Figure 14.3 models the reliability of the emergency measures, whereas the second event models the reliability of the flood defence. The effectiveness of the emergency measure is defined as the extent to which the reliability of the flood defence system is increased by implementation of the applied emergency measure.

When emergency measures are applied, a flood defence can still fail even if the emergency measure works properly. Alternatively, the emergency measure may fail and, subsequently, the flood defence may also fail. Thus, even when emergency measures are successfully applied, the flood defence can still fail, for example, when an emergency flood embankment with sandbags overflows.

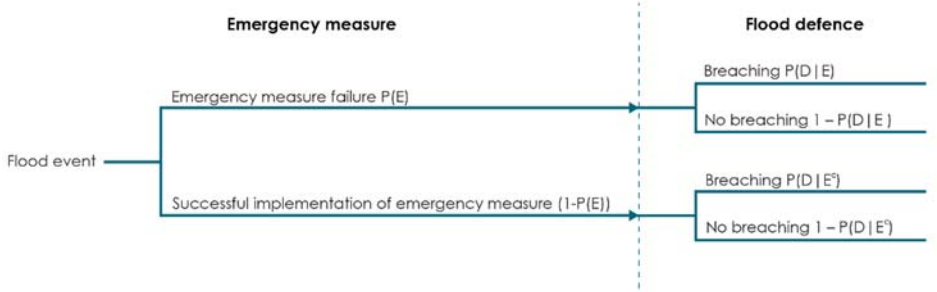

Figure 14.3: Framework to determine reliability of flood defence with emergency measures

Notes:

1. PI = probability of failure of the emergency measure.
2. P(D | E) = probability of a breach given that the emergency measure failed.
3. P(D | E^c) = probability of a breach given that the emergency measure was successful).

The reliability of a flood defence system given implementation of emergency measures is determined by following four steps:

1. Determine the failure probability of emergency measures [P(E)].
2. Determine the failure probability of the flood embankment given failure of emergency measures [P(D | E)]. (This is the same as the failure probability of the flood embankment without emergency measures.)
3. Determine failure probability of the flood embankment given successful implementation of emergency measures [P(D | E^c].
4. Determine the combined failure probability of the flood embankment given implementation of emergency measures.

For Step 2, the failure probability of the flood defence system without emergency measures is determined using probabilistic methods. For this purpose, the flood defence system is divided into sections with similar strength properties. [For each section the failure probability is determined. The resulting failure probability of the entire flood defence system may be calculated by combining results for the individual sections, taking dependencies into account (see e.g. Vrijling, 2001; Jongejan & Maaskant, 2013; van Westen, 2005).

For Step 3, a similar method is used to determine the failure probability of a flood embankment given successful implementation of emergency measures, taking account of the change in the strength properties due to the emergency measure. For example, sandbags on top of a river flood embankment increase the retaining height, which increases the resistance of the flood defence to overflow. However, this also reduces the resistance of the flood embankment to landside slope instability (see also Chapters 9 and 10).

14.1.2 Reliability of the emergency measures

The method to determine the reliability of the emergency measures is as follows. The implementation of emergency measures is divided into three phases: 'Detection', 'Installation' and 'Operation'. The probability of a correct functioning emergency measure depends on the successful completion of all these three phases: Detection – Installation – Operation (after Dupuits, 2011).

Each of the three phases is further explained below.

1. In the 'Detection' phase, the upcoming high water is monitored, and the flood embankments are inspected to find possible weak spots, such as:
   a. sand boils indicating a backward erosion piping failure mechanism.
   b. locations where the retaining height is too low.
   c. cracks in the flood embankment indicating mass instability of an embankment slope (see e.g. Figure 14.4).

   Failure if defined as failing to detect all weak spots and emergency actions are therefore not deployed.
2. In the 'Installation' phase, the required emergency measures are installed. Failure is defined as failing to install the required emergency measures correctly or within the available time.

3. During the 'Operation' phase, the emergency measure needs to function correctly to effectively prevent further damage to the flood defence. Failure can occur, for example, due to instability of the sandbags or overflow.

Figure 14.4: Cracks in the flood embankment (STOWA, 2021)

The system is modelled in an event tree forming a series system, see Figure 14.5. Failure of one of the sub events leads to failure of the emergency measure.

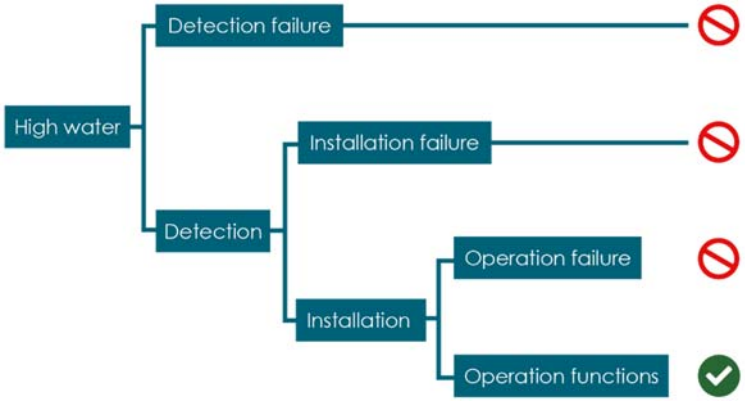

Figure 14.5: Event tree emergency measures

Both detection and installation can fail in two ways: i) human error and ii) failure due to insufficient time. 'Operation' is only subject to failure of the emergency measure to fulfil its flood defence function. Flooding will however only occur if the flood defence breaches, which may occur if the emergency measure fails, but also if the emergency measure is successful and the flood defence still fails.

Human failure during detection and installation: failure to perform the required tasks correctly.

The first category of failure modes of emergency measures is failure to either detect or install the emergency measure correctly. The reliability of the detection and installation depends on how well the emergency workers perform their tasks. Due to lack of an adequate database of human error probabilities, the probability of errors must be determined by expert judgment in combination with limited numerical data (de Corn & Inkabi, 2013). Most human reliability studies only identify orders of magnitude of errors (Bea, 1998; Rasmussen, 1982), the most important aspect of such studies being the qualitative analysis of the system (Rasmussen, 1982).

To estimate typical failure rates of the 'Detection' and 'Installation' phase for emergency measures, the method of Rasmussen applied. Rasmussen uses a generic psychological classification of human behaviour and corresponding error rates which can be applied to the performance of specific tasks (Rasmussen, 1982). The relation between common error rates and three performance levels is shown in Figure 14.6. This figure also shows a classification of main stakeholders involved in the implementation of emergency measures for river flood defences.

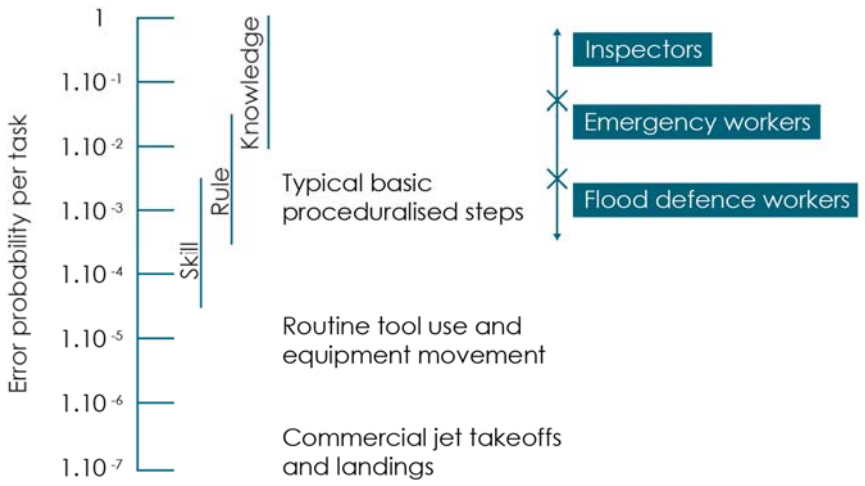

Figure 14.6: Human error probabilities and performance levels by Watson and Collins (after Bea, 2010)

The model distinguishes between three levels of behaviour: Knowledge-based, Rule-based and Skill-based behaviour (Rasmussen 1983):

- Knowledge-based performance is the most cognitively demanding level; at this level there are no pre-planned actions which can be called upon because of the novelty of the situation. The assessor is required to analyse the unfamiliar situation, develop alternative (conceptual) plans and choose the plan which is considered to be the best alternative (Rasmussen 1983). Error rates can vary between $5x10^{-1}$ and $5x10^{-3}$ per task.
- Rule-based performance is the next cognitive level; this level involves responding to a familiar problem according to standardized rules. The rule applied is selected from previous successful experiences (Rasmussen 1983). The error rates vary between $5x10^{-2}$ and $5x10^{-4}$ per task.
- Skill-based performance is the least cognitively demanding level; at this level the demands of the situation occur so often that knowledge retrieval and action are virtually automatic. Normally, skill-based performance occurs without conscious attention or control (Rasmussen, 1982). The error rates vary between $5x10^{-3}$ and $5x10^{-5}$ per task.

The main stakeholders involved in the application of emergency measures are:

- The inspectors on the flood embankment, for inspection of the emergency measures.
- Emergency workers, for installation of the emergency measures.
- Flood defence workers, responsible for day-to-day maintenance of flood defences.

Each stakeholder can be classified in one of the performance levels, based on examination of tasks, interviews, observations and expert judgment (see Figure 14.6 and Lendering et al., 2013) for further discussion.

Logistical failure: failure to complete the required tasks within the available time

The second category of failure modes of emergency measures is failure to detect a problem and/or install the emergency measure within the available time (see discussion on trigger levels in Chapter 3). The timeline for problem detection and installation of emergency measures is illustrated in Figure 14.7, where the available time is defined as the time until flood embankment failure, taken to be the time available between the prediction and arrival of the peak of the expected water level. This peak can be predicted hours (e.g. storm surge / rain) to days in advance (e.g. river floods), depending on the hydrologic system under consideration (see Chapter 5).

The accuracy of the predicted water levels increases as the peak of the river flood comes closer. As an example, a distinction is made between the available time for overflow or backwards erosion piping or mass instability. Overflow will occur when the water levels exceed the flood

embankment height, during the peak of the river flood. This moment can be predicted relatively accurately. Backwards erosion piping or mass instability, however, can occur at lower water levels, before the peak of the river flood arrives; here the timing depends on the strength of the flood defence.

Inspection and intervention timings for flood embankments in Dutch river systems

In the early stages after prediction of a river flood, more attention is paid to finding weak spots for piping and instability rather than for overflow, as Dutch flood embankments are more vulnerable to piping failure (Kanning, 2012). At a later stage, when the predictions of expected maximum water levels are more accurate, and overflow threatens to occur, more attention will be paid to measures which prevent overflowing.

To determine the probability of installation being completed on time, the available time is compared with the required time for detection and installation of the emergency measures. Whether or not the emergency measure is installed within the available time depends on the capacity of the organisation (personnel, equipment and material), the travel distances, the weather conditions and the speed of detection and/or installation. The probability of insufficient time (i.e. the required time being longer than the available time) is determined probabilistically using Monte Carlo simulations, assuming normal distributions for the available and required time.

There are many aspects that influence actual effective installation times (see discussion in Section 14.2). For example, in practice, some measures such as sandbags do offer an improvement in resistance to failure modes even when not deployed to their eventual full height.

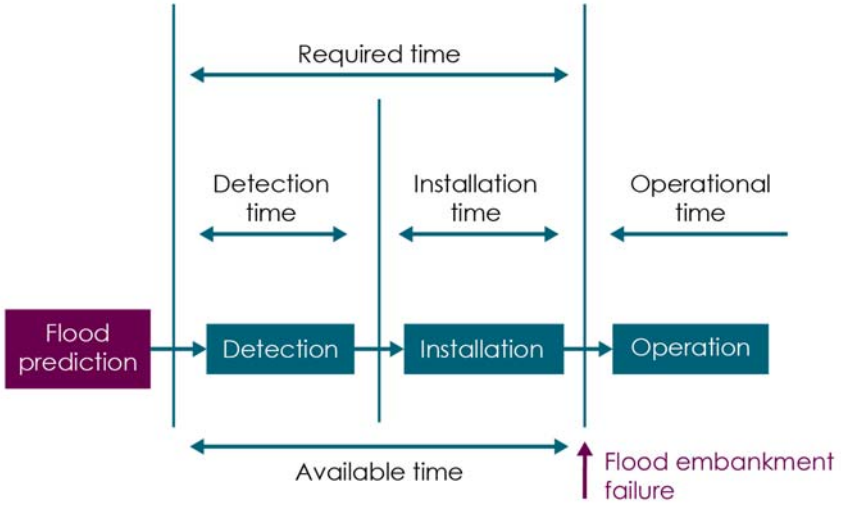

Figure 14.7: Timeline of implementation of emergency measures

Operational failure

Operational failure of the emergency measures is a hydraulic or structural failure mode occurring within the 'Operation' phase. Chapter 10 has provided a comprehensive description of various types of emergency measures with Chapter 11 providing more detailed information of some of the techniques used. All measures will be subject to uncertainties in their technical reliability during the operation phase.

Determination of probability of failure for a gravity sandbag structure

As described in Chapter 10, sandbag structure may be installed, either to raise the crest of a defence to prevent overflow or as a sand boil containment structure to stop backwards erosion piping. Figure 14.8 shows a schematic overview of loads for a schematized sandbag structure, which obtains stability largely through its own weight (W). The loads consist of the horizontal water pressure ($F_{w;h}$) and upward water pressure ($F_{w;v}$).

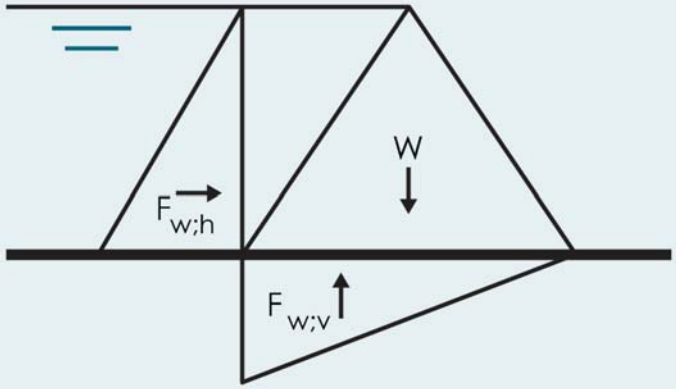

Figure 14.8: Typical loads on a schematized temporary water-retaining structure consisting of layers of sandbags.

The structures is subject to the following failure modes: overflow, horizontal sliding, rotation and seepage (Figure 14.9). The stability is largely influenced by the weight and the development of upward water pressure under the structure, which depends on the subsoil, loading time and connection between the structure and the subsoil.

Figure 14.9: Typical structural failure mechanisms of temporary water retaining structure: Overflow (1), Sliding (2), Rotation (3) and Seepage (4) (after Boon, 2007)

Assuming that these structures are constructed on impermeable subsoil on the outer layer of flood defences, instability due to sliding will be the governing failure mode (Boon, 2007). If the upward water pressure ($F_{w;v}$) is ignored due to the temporary nature of the load and the construction on impermeable clay layers, then sliding occurs when the horizontal force ($F_{w;h}$) on the structure exceeds the friction force (f) between the structure and the subsoil due to self-weight (W) (see equation below):

$$Fs_{sliding} = \frac{f \cdot (W - F_{w;v})}{F_{w;h}} > 1$$

$Fs_{sliding}$ represents the safety factor for sliding, stability is obtained when $Fs_{sliding} > 1$ (-). Probabilities of failure may be estimated using Monte Carlo simulations of the equation above.

Note that over larger lengths of these structures, failure may also occur due to bad interconnections between single elements within the structure. The same equation can be used as failure between singular elements of sandbags will be caused by the same sliding failure mechanism.

Effectiveness of the emergency measures

A probabilistic method is used to determine the failure probability of the flood defence system given successful implementation of emergency measures, by simulating the increased strength properties of the considered section with the implemented emergency measure. For example, the installation of temporary water retaining structures on top of a river flood embankment is evaluated by modelling an increase of the retaining height of the considered section. This will result in a lower probability of failure than without the temporary structure, due to the increase of strength for overflow.

The extent of the reduction of the failure probability depends on the type of measure and the failure mode of the flood defence. The conceptual fragility curves (see explanation in Chapter 9) in Figure 14.10 show the failure probability [P(f | h)] of the flood defence conditional on the water level, for the failure modes overflow and piping. It illustrates the potential increase in reliability for both failure modes after successful implementation of an emergency measure. As can be seen, temporary measures for overflow mainly reduce the failure probability of the section for water levels close to the crest, while piping measures can potentially reduce the failure probability at lower water levels. This is mainly due to the original shape of the fragility curve.

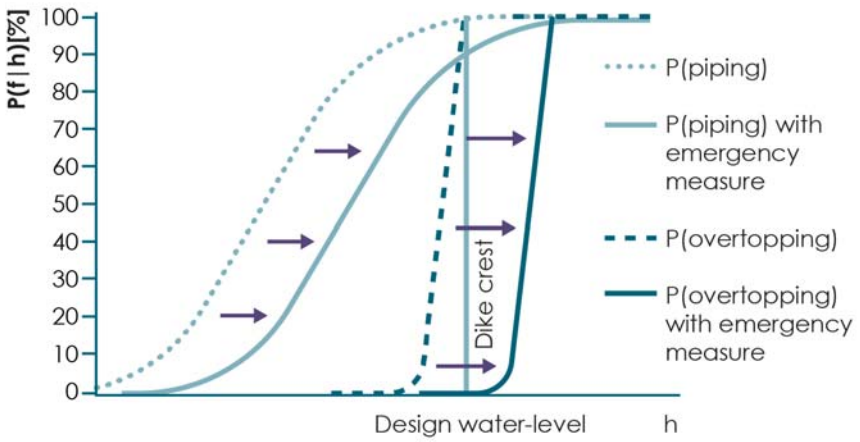

Figure 14.10: Example of a typical fragility curve for river flood embankments

Combined failure probability flood defence

The sub events which determine the reliability of the emergency measure are integrated with the general event tree to form an integrated event tree (Figure 14.11). The integrated event tree is used to determine the failure probability of a flood defence system with implementation of emergency measures. Failure due to insufficient time during 'Detection' and 'Installation' is considered a separate failure mode, which is modelled in the integrated event tree with a separate sub event.

The only combination of events in which the emergency measure is successfully implemented reducing the failure probability of the flood defence is the bottom branch, shown in the Figure 14.11 in green In all other branches, the failure probability of the flood embankment without emergency measures must be considered, as the emergency measure is not successfully applied.

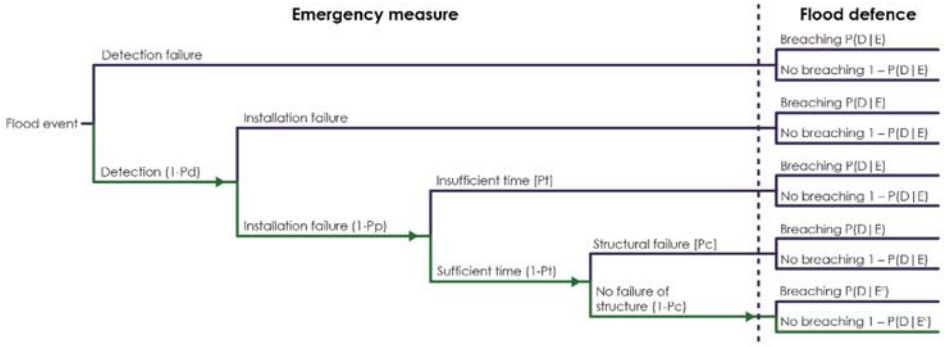

Figure 14.11: Integrated event tree for assessing the reliability of a flood embankment section with emergency measures.

It should be noted that one emergency measure may increase the resistance against one failure mode but may endanger failure by another mode. For example, when a flood embankment sustains higher water levels due to sandbags on the crest, the weight loading driving mass instability increases and may endanger failure by this mode. Furthermore, whether an emergency measure reduces the overall likelihood of failure of a flood defence strongly depends on all the factors discussed earlier (human error, available time, the emergency measure, availability and skill of emergency workers, materials availability and the defence itself).

14.1.3 Examples of reliability of emergency measures during a flood event

As explained in the previous section, failures of flood defences despite emergency measures may arise during any one of the stages in the implementation of failure detection and implementation of emergency measures. In this section we provide call-out boxes that describe three examples of emergency measures during flood events, where issues with the reliability of emergency measures arose at different stages. Figure 14.12 summarises at which stage failure arose in each case.

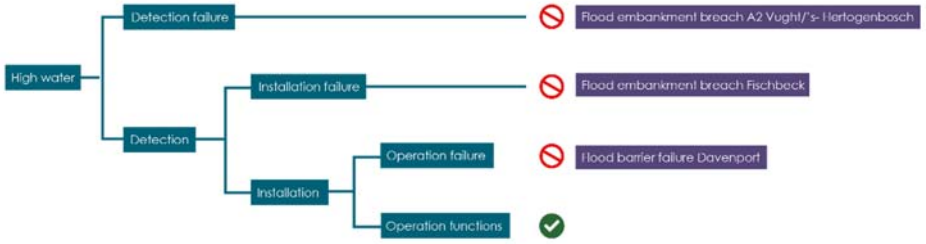

Figure 14.12 Emergency measures failures for the different examples in the call-out boxes below

Managing defence failures in the Netherlands during the high waters of 1995 (including embankment breach A2 Vught)

During high waters in the Netherlands in January and February 1995, the Dutch River area faced high discharges and elevated water levels due to prolonged rainfall upstream. 200,000 people living in flood-prone areas along the Rhine, Meuse and Waal were evacuated. Fortunately, there were no major consequences, attributed to the accurate detection of risks in flood defences and the correct installation and operation of emergency measures. (TAW, 1995).

At numerous places along the Rhine and Meuse emergency measures were implemented to prevent flood defences failing. One such measure was the construction of a supporting berm near Angeren along the Pannerdensch Canal. Calculations had indicated that the landward slope of the flood embankment was susceptible to mass instability, potentially leading to a breach. Timely detection and analysis revealed that the flood embankment had a significant risk of failure under the prevailing high-water conditions. This was confirmed when, along the Waalbandijk flood defence near Ochten, a crack with a length of 20 to 30 meters was discovered in the pavement, which quickly expanded to 200 meters. (TAW, 1995). Alarm was raised, after which installation of a sand berm (Figure 14.13a) was initiated on the land side to stabilise the landward slope.

On the river side of the flood embankment a weak spot in the surface cover was detected and a nylon cloth weighted with sandbags attached (Figure 14.13b - see Section 10.5.1 for details of the approach). Here too, the emergency measures were placed successfully and in time. (TAW, 1995).

However, in the Dommel catchment area, the water level rose dramatically until the Dommelkade flood defence between Vught and 's-Hertogenbosch breached, allowing unrestricted water flow toward the Bossche Broek (Buijks, 2011). Quays along the Dutch National Highway A2 also collapsed, leading to the flooding of this important traffic artery (Figure 14.13c), which remained closed for two weeks (TAW, 1995). In this instance, the initiation of failure of the Dommelkade flood defence was not detected in time, resulting in a lack of timely implementation of emergency measures.

Figure 14.13a: Operation of a support berm at Angeren (The Netherlands) to prevent sliding of the inner slope (TAW, 1995)

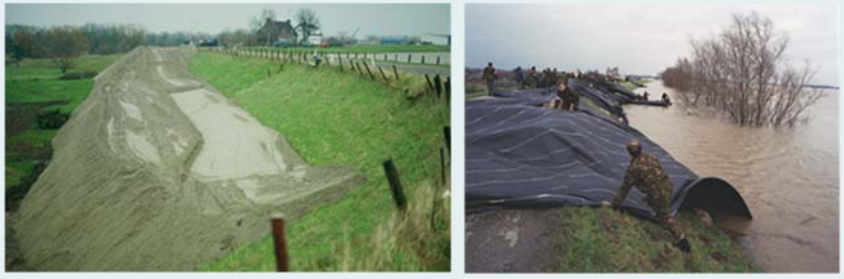

Figure 14. 13b: Operation of an inner flood embankment support berm and attachment of nylon cloth on the river side of the Waalbandijk near Ochten (TAW, 1995; source: Rijkswaterstaat)

Figure 14.13c: Flooded Dutch National Highway A2 between Vught and 's-Hertogenbosch after the breakthrough of the Dommelkade flood defence (Henk Buijks, 2011; TAW, 1995)

Flood embankment breach at Fischbeck in the Elbe River in June 2013

Spring of 2013 was an exceptional wet period in Central Europe with precipitation rates about 2.2 times higher than long-term averages for this period of the year in the German state of Sachsen-Anhalt. Intense rainfall during the last days of May and the first days of June, combined with extremely high soil moisture levels, resulted in rapid runoff of precipitation into the waterways, leading to elevated water levels (Merz et al., 2014; Sachsen-Anhalt, 2018).

During this high-water event, multiple flood embankment breaches took place along the Elbe River in Germany (Heyer & Stamm, 2013), of which the flood embankment breach at the village of Fischbeck on the night of 10 June is a notable one. At the time of the breach, a water level of 8.36m was measured at the Tangermünde gauging station, surpassing the station's previous record by 0.68m (Jüpner & Weichel, 2013). On the morning of 9 June, cracks (see Figure 14.14a) were found on the flood embankment crest running parallel to the flow direction (Sachsen-Anhalt, 2018), interpreted as signs of inner slope sliding (Jüpner, 2024). From this point onwards, efforts by the fire department, soldiers and volunteers began, involving the placement of sandbags along a 50m stretch of the inner slope to stabilise the flood embankment (Sachsen-Anhalt, 2018). Despite this emergency measure, the inner slope continued to slowly slip away, causing the flood embankment crest to 'sink' (Jüpner, 2024). As water levels rose and the first water began seeping over the flood embankment, sandbags were placed on top of the flood embankment (Figure 14.14b) to raise the crest over a length of 30 meters to prevent further overtopping (Sachsen-Anhalt, 2018). However, the weight added by the sandbags on the already unstable flood embankment, together with insufficient counterweight from sandbags on the inner slope, increased the vulnerability of the flood embankment to collapse (Jüpner, 2024). Around 21:00hrs, erosion of the flood embankment crest began, culminating three hours later in a breach of the flood embankment (Figure 14.14c).

Sandbags were placed on the inner slope as soon as cracks were detected on the flood embankment crest, indicating that detection of weak spots in the flood defence had been timely. Subsequently it was detected that the flood embankment crest was slowly sinking, prompting the response by placing sandbags on the crest of the flood embankment. While the detection phase proceeded smoothly, mistakes were made in the installation phase during the sandbag placement on the flood embankment crest and, as explained above, the weight of the bags proved to be detrimental to the stability of the flood embankment with disastrous consequences.

a *b* *c*

Figure 14.14a: High water level at the flood embankment with visible cracks in the flood embankment crest.

Figure 14.14b: Sandbags placed to stabilise the inner flood embankment and heighten the flood embankment crest.

Figure 14.14c: Flood embankment breach near Fischbeck

Operational flood barrier failure Davenport, Iowa

On 13 March 2019, forecasts indicated that water levels along the Mississippi River in downtown Davenport, Iowa, were expected to reach 5.48 meters, surpassing a trigger flood stage of 4.57m. In response, the City of Davenport erected a temporary flood barrier using the HESCO basket system. This system consists of wire basket cells with a felt lining inside, filled with sand to provide protection against flooding. Multiple sections, each consisting of 5 cells, are connected using spiral wire corner connections and metal pins. (Department of the Army, 2019)

Water reached the HESCO barrier at a flood stage of 5.48m. The first peak in river levels occurred on 8 April 2019 at a flood stage of 6.30m, a hydrostatic load of approximately 0.82m of water on the HESCO barrier. From 9 April onwards, river levels slowly fell until 24 April, when the river level began to rise again. On 29 April, the forecast for 30 April to 2 May was a peak river level of 6.77 meters, which would overtop the HESCO barrier by 0.22m. In response to this forecast, city crews added sandbags to the top of the barrier. The sandbags (Figure 14.15a) provided an additional protection up to an estimated flood stage of 7.01 meters (Department of the Army, 2019)

The weather on 30 April brought heavy rain and thunderstorms to Davenport. The HESCO barrier failed that day at a flood stage of 6.61m, 0.4m centimeters below the highest point of the sandbags. According to an engineering evaluation performed by USACE, a stability sliding failure was the most likely failure mode of the barrier. The barrier section at the failure location began to slide (Figure 14.15b), until the slack in the spiral wire connections between the HESCO baskets was gone. At this point, the sliding in the barrier was stopped by the stationary adjacent sections, but the kinetic energy and momentum created by the initial slide combined with its high center of gravity, exacerbated by the placement of sandbags on top of the baskets, caused the barrier to rotate and overturn (Figure 14.15c), resulting in failure (Department of the Army, 2019).

Figure 14.15a: Barrier section remaining after failure.

b

c

Figure 14.15b: Remaining fill sand along the failed barrier.

Figure 14.15c: Failed and overturned wire baskets at the basket connections.

14.2 Time scales within emergency response

The application of emergency response measures during high water crisis is prone to uncertainty, since the location where the measure should be applied and the total amount of material required to repair the damage is not known in advance. For that reason, it is important to include the parameter of time into the reliability analysis of emergency measures. Figure 14.16 shows the development of damage, defined as erosion or deformation of a flood embankment (system) over time. The figure shows both the time required and the time available.

- The time required is the total time needed to successfully install an emergency response measure at the required location. This time includes the time required to detect a weak spot on the flood embankment, decide whether to repair the local damage, transport the materials/components of the measure to the damage location and install the measure.
- The time available finishes at the point where a damage can no longer be mitigated (e.g. the damage dimensions or flow velocities through the damage become too high).

Implementation of an emergency measure can only be successful if the time required is smaller than the time available.

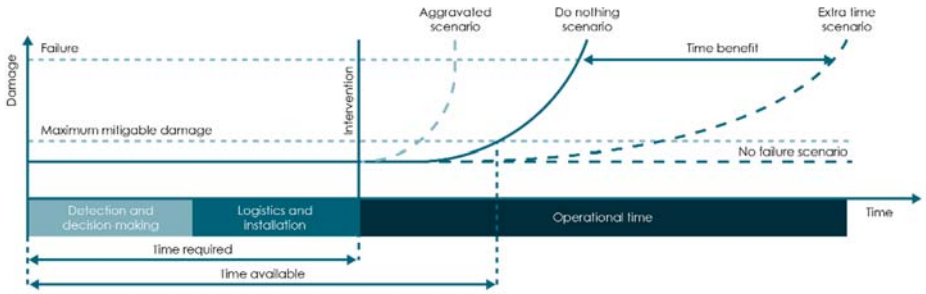

Figure 14.16: Time requirements for emergency response measures (after Janssen et al., 2021)

If the damage threshold level for failure is exceeded, the flood embankment is not able to fulfil its main purpose anymore, which is to retain water. Intervention within the damage process can progress according to four types of scenario (Figure 14.16):

- 'Do nothing scenario', which occurs when not intervening in the damage process.
- 'No failure scenario', in which the progression of damage over time completely stops.
- 'Extra time scenario', where the damage to the flood embankment continues to progress, but the time to failure also increases beneficially compared to the first scenario.
- 'Aggravated scenario', in which the time to failure of the flood embankment decreases becoming much closer to the time required. This scenario should always be avoided.

Once a prediction of an extreme water level has been received, the total time required to complete an intervention can be obtained by assessing the time required for each of the following sequential steps:

1. Two parallel processes:
   a. Inspection and detection of a damage on the flood embankment. This includes the time required for:
      - Decision to increase physical inspections on the flood embankment.

- Travel of inspectors to the flood embankment.
- Detection of damage on the flood embankment, only possible after the occurrence of a visible symptoms of the failure mechanism.
- Decision to repair the observed damage.

b. Preparation for deployment of the emergency measure including the time required for:
   - Decision to prepare an emergency measure and its required personnel.
   - Preparation of the measure and personnel itself.

   The preparation ends when the measure is ready for deployment (from a storage location.

2. After the detection of a damage and preparation of an emergency measure, the transportation and installation of the emergency measure to the required location can commence. This includes the time required for
   a. Transportation of the emergency measure from storage to the damaged flood embankment section.
   b. Installation the emergency measure at the flood embankment section.

Once the time required has been determined, the probability of being in time (or too late) can be assessed, using a model developed by Janssen (2024).

14.3 Case studies

14.3.1 Sandbag contest 2018

In the project Flood Proof Polder, Holland a contest was organised on the installation of sandbags (Figure 14.17). The goal was to gain insight into the effectiveness of sandbags with its aim to improve the design emergency measures in the event of high-water emergencies.

Figure 14.17: Impression of installation(left) and completed installation (right) during the contest

The teams that competed varied in team size, strength, experience and knowledge. The performance of a team was estimated using the OPSCHEP-model (the 'Oke Project Software for the Calculation of Human Error Probabilities' (Heslinga, 1985)), which estimated the total failure probability for each team based on team characteristics. In the model, team characteristics determine so-called Performance Shaping Factors, which then translate to a potential failure probability. The calculated probability of failure takes into account:

- Logistic, placement and final shape of the installation.
- The building capacity of each team.
- Failure of the measure during operation.

Dutch Army teams, with their trained staff, built sandbags faster compared with the other teams. During the contest, the capacity decreased most in teams with less experience and stamina. The effectiveness (building capacity) has been calculated as contribution for each team member and differed from 4 to 11 sandbags in 5 minutes, noting that building speed did not guarantee stability.

The probability of failure has been estimated by the OPSCHEP model using Performance Shaping Factors that take account of

- Conditions at the start, like working instructions, procedures and complexity.
- Team and task, material aspects, experience and skills, including their fitness/ capacity.
- The team characteristics, background and experience in the field (civil engineering) and knowledge of the failure modes the available time for their tasks.

The experiment revealed a potential difference of a factor 65 in probability of failure depending on the distance to be covered and knowledge of the teams involved (i.e., if they received good instructions). Probabilities of failure were smallest (0.004) for teams with high knowledge on placement of the sandbags. The highest probability of failure (0.26) was for a team that had to cover large distances, had no knowledge and didn't receive working instructions, resulting in the first dam failure. Failure was caused by incorrect placement, leading to water flow between the sandbags.

The experiment confirmed how important it is to provide good instructions during emergencies.

14.3.2 Flood embankment Salland

Lendering et al. (2013) undertook a case study for a Dutch regional water authority, near the city of Zwolle in the Netherlands. The studied flood embankment, named 'Salland', can be seen in Figure 14.18. The failure probability was estimated by van Dijk & van der Plicht (2013) as greater than 1/100 per year, driven by a high probability of backward erosion piping. The regional water authority acknowledged these problems with piping, as it is known that, along several parts of the flood embankment, numerous sand boils often occur during high river discharges.

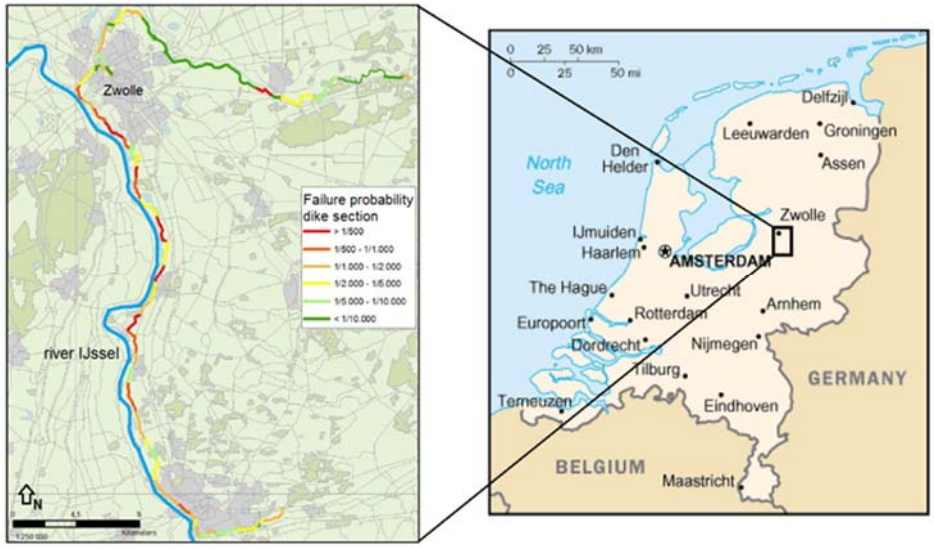

Figure 14.18: Case study area with failure probabilities of flood defences (left) (van Dijk & van der Plicht, 2013)

The regional water authority receives predictions of river floods several days in advance and uses these to decide whether it is necessary to inspect the flood embankments. If necessary, the flood embankment watch is instructed to perform inspections of the flood defences and report weak spots directly to the flood embankment supervisors of the water authority. The flood embankment supervisors then decide whether to install emergency measures. If required, a contractor installs the measures. Using interviews and observations, estimates were made of the performance levels of the various stakeholders.

The probability of failure of complete installation within the available time was determined by using:

- Data made available by the regional water authority about the amount of time required for installing emergency measures.
- The available time was assumed to be 2 days for overflow measures and 4 days for piping measures.

Van Dijk & van der Plicht (2013) conducted sensitivity analyses to determine the failure probability of the flood embankment with and without successful implementation of emergency measures. Emergency measures addressed both overflow and piping failure mechanisms; in the latter case the measures were based on reducing the head of water across the flood embankment by 0.5m. Failure probabilities were estimated at the ten weakest sections of the flood embankment. The results are shown in Table 14.1

Table 14.1: Case study results

Variable	Overflow	Piping
Failure probability of emergency measure	1/9 per event	1/3 per event-
Failure probability of flood embankment without emergency measure	1/600 per yr	1/60 per yr
Failure probability of flood embankment with emergency measure	1/3,600 per yr	1/150 per yr
Failure probability of the system	1/2,400 per yr	1/100 per yr

The distribution of factors which determined the failure probability of both piping and overflow emergency measures are shown in the pie charts in Figure 14.19.

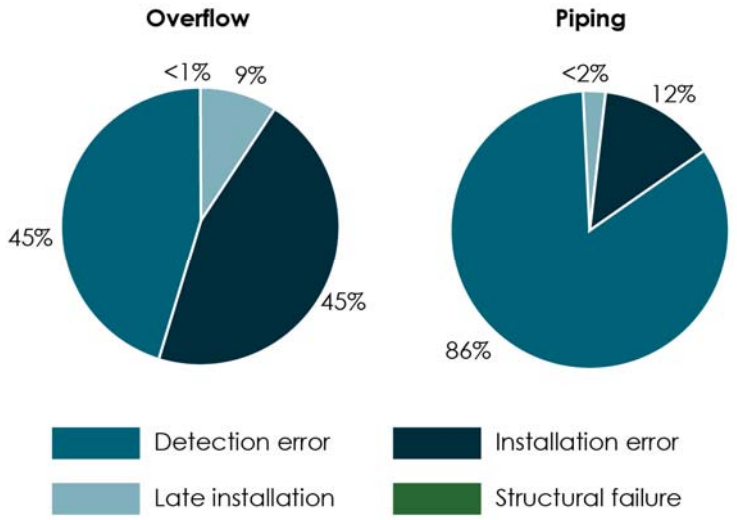

Figure 14.19: Contributions of factors that determine the probability of failure of the emergency measures for overflow and piping

14.3.3 High water exercises – Regional Water Authority Brabantse Delta

This example is based on information used in exercises representing high water emergencies associated with flood embankments in the area of the Regional Water Authority Brabantse Delta, in the South of the Netherlands. The information available included:

- Actual and predicted water levels (see Figure 14.20.
- Information of flood embankment parameters.
- Expert judgements of the employees of the regional water authority.

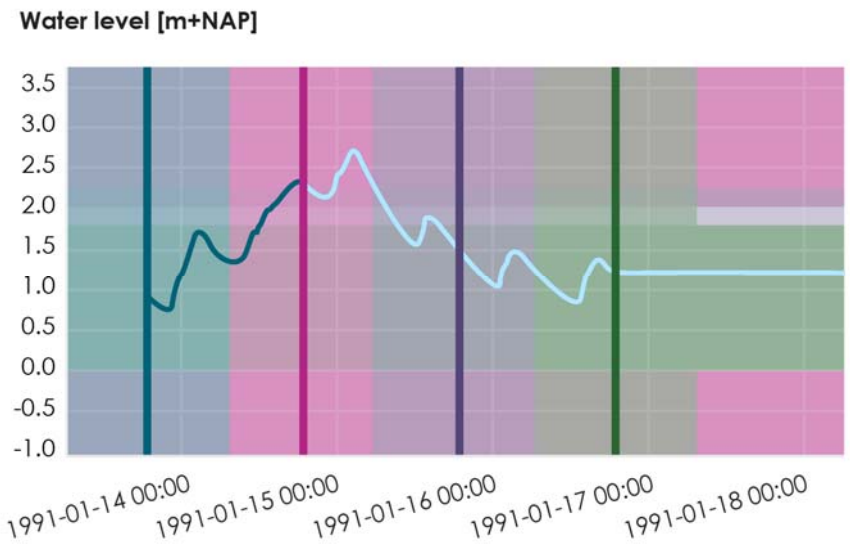

Figure 14.20: Actual and predicted water levels for station Rak_noord

The flood embankment failure probabilities were estimated and plotted on the embankment locations, grouped into four classes: safe (green), warning (yellow), dangerous (orange) and critical (red) – see Figure 14.21. (The associated flood risks in terms of casualties and damage in the area defended by the flood embankments are also calculated and shown in classes.) Weak spots are those flood embankment sections with the largest failure probabilities, but also those which lead to many casualties or large damage.

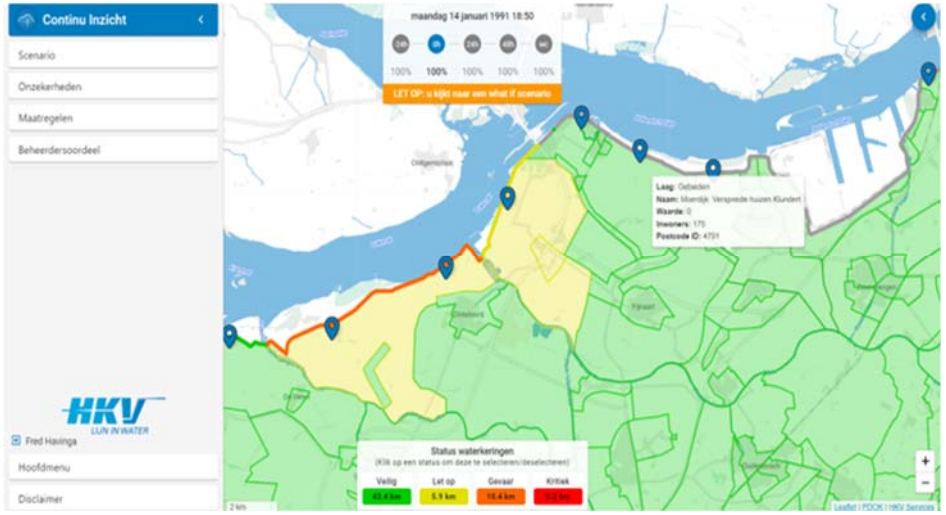

Figure 14.21: Overview of actual flood probabilities and flood risk, plotted in safety classes

In Figure 14.21, one section of the flood embankment has a large failure probability, classified as dangerous (orange). A potential breach of this flood embankment section leads to higher flood risks (yellow) than surrounding areas (green).

Based on this information, the crisis team were able to make decisions about emergency measures to temporarily strengthen the flood embankment. The fragility curve for this flood embankment section, based on the dominant failure mechanism of backward erosion piping mechanism is shown in Figure 14.22.

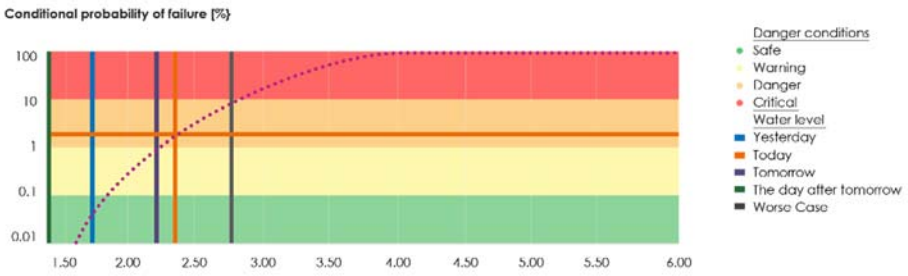

Figure 14.22: Fragility curve flood embankment section 34-4 piping for yesterday, today and the next days

From this figure it appears that, for today's water level of 2.4m, the flood embankment has a failure probability of 1.7%. If this probability is to be reduced to a safe value (here green), the probability should be lowered to no greater than 0.1 %.

In the exercise scenario, to prevent sand boils from growing, containments are built around the boils with temporary water retaining structures, typically consisting of sandbags. As explained in Chapter 10, these containments fill with seepage water providing counter pressure and thus reducing the flow velocity and further erosion of sand particles. Assuming the containments are installed successfully, the water head across the flood embankment is reduced by 0.5 meter leading to the reduced failure probabilities shown in Figure 14.23.

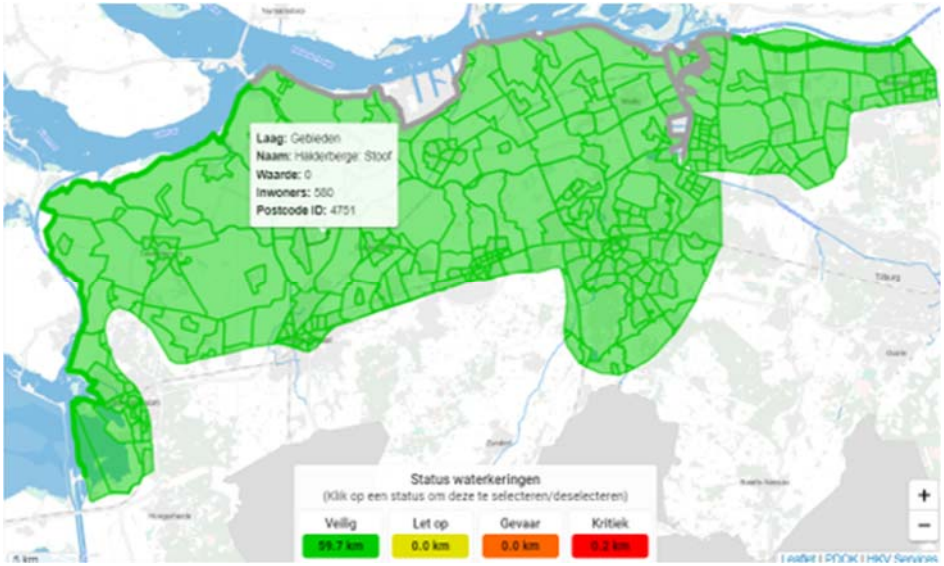

Figure 14.23: Reduced flood probabilities and flood risk after successful emergency measures

However, an emergency measure is only valid in case of successful detection, installation and operation. Not only therefore should the effect of successful implementation of the measure be quantified, but the following effects should also be considered, as described earlier in this chapter:

- (Early) detection of sand boils in the field is the most significant factor (86% contribution in the case of Salland in Section 14.4.2) in determining the failure probabilities for backward erosion piping.
- Accurate information arriving with the team making the decision at the Emergency Operations Centre.
- Correct installation of the emergency measure.

14.3.4 Fictional case study of a hospital

This case study examines the fictional case of a large hospital complex built in an area of about 0.24 km2 which has subsided approximately 2

meters below the surrounding area. The hospital facilities cover about 75% of the total area. The area is subject to tropical rain showers which can result in flash flooding due to insufficient drainage capacity in the surrounding area. Statistical analysis of rainfall intensities resulted in the intensity-duration-frequency (IDF) curves shown in Figure 14.24.

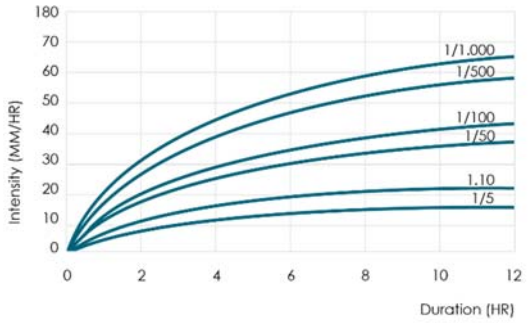

Figure 14.24: Intensity-duration-frequency curves for fictional case study of a large hospital complex.

Using the intensity-duration-frequency curves for rainfall, return period water levels were estimated for the area, as shown in Figure 14.25. We assume that the system is closed, and that negligible infiltration is occurring.

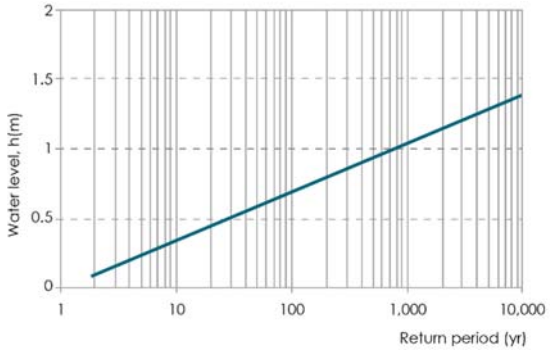

Figure 14.25: Return period of water levels (left) and flood damage estimates (right) expressed as a fraction of the total value of the hospital complex.

To reduce flood risk to the hospital complex, temporary flood barriers were applied to protect the hospital entrances to prevent it from flooding. Rather than sandbags, the protection is provided by water-filled tubes which provide protection up to their design height, typically 0.5m (see Figure 14.26), obtaining stability through the weight of water filling the tube. Figure 12.26 shows return periods of flood levels with the water-filled tube barrier in place (left) and corresponding damage estimates for the situation with the tube barriers (dotted line) compared to the baseline situation.

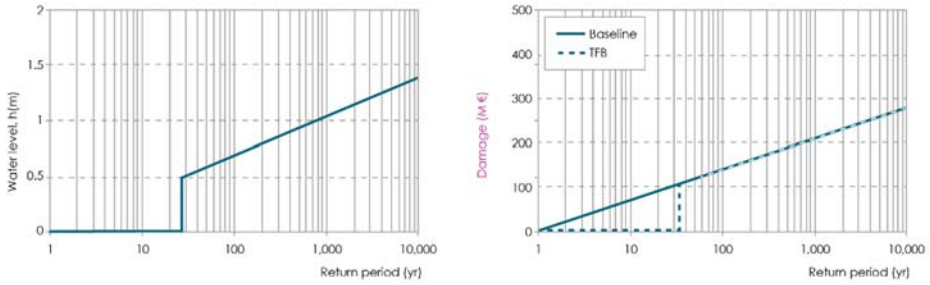

Figure 14.26: Return periods of flood levels with temporary flood barrier in place (left) and damage estimates for a situation with temporary flood barriers (dotted line) compared to the baseline situation.

To assess the probability of failure of the temporary flood defence, both installation and operational failure were considered.

- Installation failure could occur due to operator error or logistical failure (i.e., failure to transport the innovation to the required location), with operator error being the dominant failure mode.
- Operational failure could occur due to instability of the tube (e.g., due to sliding or turning over), ruptures of the canvas material, or seepage/leakage under the tube.

Figure 14.27 illustrates a fault tree for the tube barrier. Note that this is a series system with OR gates, so all elements need to be successful to ensure adequate overall performance of the system. Table 14.2 describes and evaluates the effectiveness and reliability of the protection measures.

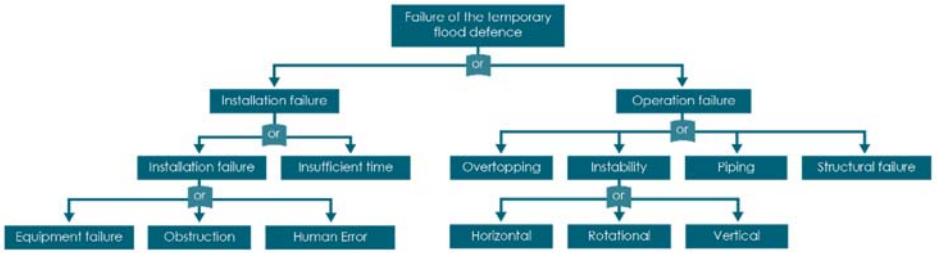

Figure 14.27: Example fault tree for a temporary flood defence (TFD)

Table 14.2: Assessment of the water-filled tube barrier in terms of each performance indicator.

Indicator	Description	Variable	Value
Effectiveness	The effectiveness of the temporary flood barrier is defined by its ability to provide protection up to 0.5 meter, which corresponds to protection up to the ~1/20 year event.	ΔP_f	1/20
Reliability	The operator error impact on reliability is estimated to be 1/50 per task (see Lendering *et al*, 2018) assuming the operator operates at a rule-based level (see earlier Figure 14.6). Sliding will be the governing failure mechanism given the smooth surface of the entrance tiled floor (1/50 per use). Assuming that the implementation and technical failure probabilities are independent, the probability of failure of both failure modes can be summed. The resulting probability of failure is 1/25 per use. Assuming the barriers are applied at every 1-year event, this results in an annual failure probability of 0.04 (or 1/25).	$P_{f;innovation}$	0.04

14.4 Improving reliability of emergency measures

This chapter has shown that fault detection, installation, operation and the input of human capacity, skills and experience are all important if emergency measures are to be effective. While emergency measures can only be an interim solution to reduce flooding probabilities, a flood defence management organisation can improve the reliability of their emergency measures by applying the following steps:

1 Determining ambitions for improvement and documenting these in medium-term plans.
2 Improving the knowledge of their permanent defences and how they perform by regular inspection and documentation.
3 Improving resources and knowledge for inspectors, technical staff and decision makers in order to improve the reliability of the inspection, decision-making and installation processes.
4 Simulating high water events, to train workers in the aspects mentioned in 3, including in:
   - Detection, installation, operation and communication for flood embankment inspectors and emergency workers.
   - Exchange and interpretation of technical and field information by technical staff.
   - Organisational awareness.
   - Communication with, and advice to, decision makers.
   - Interpretation of advice and communication with emergency staff (police, fire brigade, hospital staff).
5 Evaluating actual emergencies and re-evaluating the ambition level, drawing conclusions about what has worked well or otherwise and identifying improvements at the various stages of the flood defence emergency management process.

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CHAPTER 15

Sharing knowledge and collaborating

Key messages:

- **Knowledge sharing helps mitigate floods**
- **Collaboration avoids burnout during emergencies**
- **Capture and use lessons from emergencies**

Figure 15.1: Structure of the handbook

Other places to find information on the topics of this chapter

Chapter 2: high level overview, showing how capacity building is integrated institutionally

Chapter 3: capacity building in the preparedness phase

Chapter 4: learning from the experiences in the response phase

Chapter 5: understanding the risk of flooding and how to tune capacity building to this

Chapter 6: understanding of types of flood defence and their characteristics; communities of practice and collaboration are often related to the type of flood defence

Chapter 7: understanding of the role of communication and how we can improve this

Chapters 8 through 12: understanding of the process and what needs to be learned, trained and exercised

Chapter 13: understanding of role of health, safety and wellbeing and what needs to be learned, trained and exercised

Chapter 14: understanding reliability analyses and what this means for capacity building

Chapter 16: approaches to justifying the funds for the needed capacities and capabilities

Chapter 17: guidance on how to make the handbook and the community work for you

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Note:

The Reader is kindly requested to take note of the Disclaimer on page ii of this handbook.

Chapter title page photograph:

A joint information sharing and communication exercise conducted with the participation of multiple organizations involved in disaster response (courtesy: MLIT)

Key messages

- **Knowledge sharing helps mitigate floods.** The risk posed from flood events is continuous, and a proactive and effective approach to knowledge growth and sharing is required to underpin a successful flood management system. The sharing and transfer of knowledge is therefore crucial to firstly retain, and then improve upon, the ability to manage and mitigate flood risk.
- **Collaboration avoids burnout during emergencies** (Inter)national collaboration may combat burnout risk during intense or long-lasting emergencies.
- **Capture and use lessons from emergencies.** Lessons cannot be learned unless they are first identified and recorded. Using lessons learned and case studies to develop professional education keeps professionals and organisations current, helps facilitate a shift to true learning organisations, and helps keep professional development aligned with the central tenets of adult learning. Continual improvement is a powerful way to positively affect preparedness and resilience of a flood defence management system, thereby positively affecting entire communities, organisations, and nations.

The ever-present risk and global frequency of flood events means there is continual real-life testing of flood defence systems, management, and the recovery processes. This produces a wealth of data and observations from which there is the potential to learn. However, sustaining knowledge requires proactive attention. Knowledge learnt must be continually re-learnt, and each new cohort of flood managers must gain their own experience to ensure sustainable and enduring risk mitigation for future generations. Access to a toolbox of approaches to learning is advantageous in achieving good knowledge transfer.

Experience gained from real events and exercises, especially when integrated with scientific research and technological advances, is integral to flood risk management. It can be challenging, however, to fully realise this value during an emergency. Collaboration between organisations and countries offers the opportunity to access a wider pool of experience from which to learn. Gaining experience from lessons learnt is a core aspect of any preparedness system. However, lessons cannot be learnt unless they are first identified and recorded, requiring active mechanisms to identify, capture, and analyse new information or issues and convert them to new understanding and knowledge over time. Learning can be particularly effective when people are in a safe environment, such as during an exercise or when training in a living lab.

When seeking joint learning and mutual support across cultures, it is important to understand the protocols, particularly cultural, that might otherwise constrain effective co-working and knowledge transfer.

Given this context, this chapter includes the following:

- Section 15.1 provides insight into the valuable mechanisms available to grow expertise through knowledge sharing.
- Section 15.2 discusses the importance of sharing experiences and peer reviews in achieving continual improvement in the management of flood defence emergencies.
- Section 15.3 describes the way by formal training processes and exercises enhance knowledge transfer and growth.

- Section 15.4 provides guidance on important considerations when seeking co-learning and when requesting or offering assistance.
- Section 15.5 introduces the concept of living laboratories to progress technical and social innovation.

15.1 Knowledge sharing mechanisms

Knowledge can mean many different things to different people and cultures. This section provides insight into what knowledge is, and some valuable mechanisms available to achieve effective knowledge sharing.

15.1.1 What is knowledge

Weggemans (1997) defined knowledge as the personal ability to perform a particular task. That ability can be seen as some combination of information (or professional knowledge), experience, skills and attitude. In other words:

Knowledge = function of (information, experience, skills, attitude)

In other words, for an individual or group to be able to perform a certain task effectively and efficiently in any situation, they need:

- **Information**: explicit knowledge obtained by sharing guidelines, models, toolboxes, etc.
- **Experience**: seen it, done it, know how to act even in extreme or uncertain situations.
- **Skills**: the combination of the knowledge (knowing what) and ability (knowing how) to perform a task without making mistakes.
- **Attitude**: The collection of emotions, thoughts and beliefs that determine an attitude towards what has been learned, towards colleagues, stakeholders or new developments. Personal motivation and environment are important. It is about taking your responsibility as a person, but also taking care of the health and safety of the individual and the group.

Experience, skills and attitude are both tacit and explicit (Collins, 2010), for as Polanyi (1967) stated: “We know more than we can tell”. Through mechanisms such as partnerships, platforms, forums and communities of practice, they all play an important role in sharing and building knowledge as well. Consider the following:

- **Experiences**. We can use our own experiences to tell our stories, to learn by visiting other flood defences and share in their experiences, and to build our relationships and professional networks. Inviting colleagues and peers to observe flood fighting exercises is also a great way to use and build experience within and across communities of practice.
- **Skills**. As discussed in Section 15.2, there are several methodologies and best practices that may be used to build and increase skills, including education, training, and deliberate and recurring exercises. Weaving together a combination of all these methodologies, as well as creating and seizing opportunities for cross-organisation and cross-border opportunities, will build a strong foundation for skill-building within any organisation.
- **Attitude** is important in sharing and building knowledge. Feeling and understanding the magnitude of flood risks and understanding your personal role in managing the risks is key to maintaining the positive attitude required to sharing what we have learned. The best leaders are those who are responsible and act accordingly, who inspire their teams to operate successfully and safely, and most importantly, have the positive attitude that allows their teams to do all those things while still offering the space and grace to learn and share lessons.

15.1.2 The power of collaboration

Learning by sharing experiences of managing flood emergencies.

Although floods are devastating events with immense impact, for most countries and areas, the probability of an extreme flood is low, with a return period of some decades or more. Although it is to be expected that climate change will increase the frequency of extreme floods (IPCC, 2021), flood defence management personnel with the most flood fighting and flood risk management experience may be retired or have changed jobs in between major flood events. A new generation of motivated but perhaps non-experienced or less-experienced experts will have started their job by the time the next major flood event occurs and need to gain the same knowledge (see Section 15.1.1) as their predecessors.

As a result, every flood defence emergency management organisation needs a team that is trained to an Olympic level, even though they may never know if they will play the game. They may also have had little opportunity to train within realistic scenarios. Major flood events, however, occur somewhere in the world on a very frequent basis, providing the opportunity to observe and learn from others. This is why a collaborative approach to knowledge sharing is so vital to support effective flood preparedness and management.

Managing shortfalls in capacity of flood defence emergency teams during emergencies

Another challenge teams may face is one of event burn out. Flood control can take a long time, weeks or sometimes even longer, and the condition of a flood fighting team may decrease during these enduring response and recovery efforts. Ideally, an organisation will have an "A" Team and a "B" Team, or at least enough redundant capacity that allows organisations to cycle and replace team members after a certain period. Such redundancy can prevent teams from developing event-related health issues, and it also helps teams avoid making fatigue-related mistakes. However, providing and maintaining that type of depth in an organisation may be difficult, especially for smaller and less well-funded entities.

But there is something that even the leanest organisations can do to combat this risk, and that is engage in active collaboration. If in a country, a specific region is affected, teams imported from other regions can assist and take over shifts, reducing the risk of burn out but also expanding the knowledge, skills, and experience available during a given event. If a whole country is affected by the floods, international assistance can be available. The ability to collaborate with other experts who can review approaches and potential solutions, especially in cases of complex issues, is a valuable tool in the flood defence manager's toolbox. The saying "make a friend before you need a friend" is appropriate here. It is important to know your peers and colleagues, have confidence in their expertise, and accept the expertise of the teams from abroad.

Training together as part of preparedness

(Inter)national collaboration is not just applicable during active flood events. It may also mean training emergency management teams together, which will help build confidence in the skills and experience of and between national and regional teams, keep teams motivated, and increase preparedness capabilities. Cross-border collaboration may also include:

- Sharing knowledge via staff exchanges.
- Working together to develop new and innovative emergency measures and methods.
- Proactively building and strengthening communities of practice through both formal and informal means, including shared training and exercise opportunities and hosting and attending networking and other social events, either virtually or in-person.

15.2 Continual improvement

The principle of continual improvement is a foundational component of any managed system. Continual improvement is broadly defined as the steps an organisation takes to reflect upon experience, events, and collaboration, identify lessons learned and best practices, and implement those lessons learned and best practices to improve its own organisational capacity. Sustaining and maintaining organisational knowledge over time takes a proactive and focused approach, including through deliberate training and exercises, but will pay dividends over time.

15.2.1 Maturity levels

Continual improvement is most effective when organisations first understand where they lie in terms of relative maturity across all aspects of the managed system. Depending on relative experience, knowledge, and their application during emergencies, the level of maturity will vary between elements of the managed system and between organisations. Understanding these levels of maturity should help highlight areas for greatest potential improvement.

Managing knowledge incompleteness

Knowledge will never be complete and any system or organisation will become fragile if perfect understanding is presumed, especially during emergencies. The state of experience and knowledge influences how a system or organisation responds to emergencies. Figure 15.2 demonstrates the states of knowledge from unknown to known and how this influences response. Where unknowns dominate, the response is likely to be predominantly reactive. In comparison, aspects that are well understood enable refined plans and event preparedness.

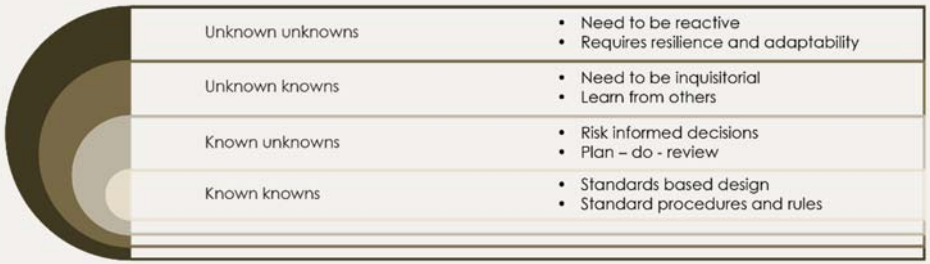

Figure 15.2: States of knowledge and approaches to managing them

When an organisation fully understands its internal maturity levels, it is better prepared and postured to obtain assistance and knowledge from others. This is a two-way process in which the organisation:

- Seeks knowledge from the wider industry through formal and collaborative forums.
- Identifies where it can best contribute to the wider emergency management network.

Maturity Matrices are a tool to assist organisations to target continual improvement. An example of a maturity matrix is the Centre for Energy Advancement through Technological Innovation (CEATI) maturity assessment tool (CEATI, 2018) for dam safety that allows dam owners to benchmark their managed system against a matrix of 12 core elements.

An example of high-level descriptors for an emergency preparedness maturity matrix is provided in Table 15.1. It is normal to include at least a second tier of descriptors specific to each maturity level within the managed system.

Table 15.1: Example of Tier 1 descriptors in a maturity matrix

Maturity Level	Descriptors
Minimal	• Limited experience with significant gaps across the managed system. • Limited if any process to drive improvement. • Relies heavily on the support of others during even relatively modest events. • Has minimal active connection within the industry outside of emergency events.
Basic	• Some experience but highly variable across the managed system. • Some basic processes to drive improvement but only in some areas. • Relies on the support of others particularly during more significant events. • Has some active connection within the industry outside of emergency events.
Emerging	• Demonstrable experience in some areas but remains variable across the managed system. • Established processes to drive some improvement but likely to be incomplete across the full system. • Relies on the support of others particularly during major events. • Has active connections within the industry used to support and grow capabilities.
Established	• Demonstrable experience across all areas but with known areas for improvement. • Established processes to drive improvement but likely across the full system. • Understands when to seek support from others during events and may assist others. • Has a comprehensive support network to grow knowledge and contributes back to that network.
Advanced	• Demonstrates high level of experience. • Has processes that fully support ongoing improvement across the entire system. • Active participant in helping others during events and for knowledge transfer. • Is a leader within the wider industry network but also draws upon the network to continue to grow.

15.2.2 Peer reviews

Gaining the perspective of others is always of value even to those with robust and mature systems. There are a range of opportunities for peer reviews, including:

- Technical reviews of the design for new or upgraded flood defences.
- Review of procedures.
- Post event reviews.
- Review of the overall preparedness system.

Audits effectively mark an organisation against its own system (Are you doing what you said you would do?) In contrast, peer reviews seek to identify opportunities for improvement and as such are best undertaken in a proactive and collaborative way with the organisation under review.

Value from peer reviews is primarily derived from the different experience and perspective of the peer reviewer. Applying these different experiences to how the emergency preparedness system might respond, the peer reviewer explores the robustness of the system and its relative maturity and identifies potential opportunities for improvement. While peer reviewers are typically conducted by personnel external to an organisation, value can also be gained from internal reviews from personnel not directly involved in the part of the managed system under review.

In undertaking a peer review, the aspects listed in Table 15.2 should be considered.

Table 15.2: Key aspects of a peer review

Aspect	Ensure that:
Scoping the Peer Review	• The objectives of the review are clearly defined and understood. • There is ample opportunity for relevant personnel to engage in the review and with the reviewer. • Cultural protocols (organisational and/or national) that may influence how best to undertake the review and how successful it will be, are appropriately accounted for. • Within the limits of the previous point, that there is an open attitude amongst all involved. • The reviewer is charged with highlighting problems and opportunities alike. • There is an opportunity to collectively discuss the outcomes of the review in a collaborate forum to help inform pathways forward.
Conducting the Peer Review	the reviewer • Requests and reviews applicable information for the system elements under review. • Conducts one or more open collaborative workshops. • Undertakes a site visit with flood management personnel to one or more defence elements managed by the flood management team. • Considers the information obtained and determines areas for improvement with, where possible, reference to industry best practice and guidance material. • Uses follow-up calls or mini workshops to refine the review and provides associated opportunities for improvement.
Delivering the Peer Review	the reviewer • Provides a written report that focuses on areas for potential improvement, providing context as to the value of such improvement. • Provides, where practical, suggestions on how these improvements might be advanced. • Preferably conducts an open & collaborative workshop to discuss the review results and mechanisms to deliver improvements.

15.2.3 From lessons identified to lessons learned

Arguably the most difficult component of the continual improvement process for any organisation is taking a lesson observed or identified and fully implementing it into practice as a lesson learned. This requires a phased approach to continual improvement in which organisations:

- Work through discovering and validating issues and best practices observed and identified during events and exercises.
- Resolve validated issues during the preparedness phase by implementing solutions and best practices into standard operating procedures, processes, doctrine, and training to improve emergency management practices and efforts during subsequent events.
- Evaluate solutions implemented during subsequent events to ensure that the solution adopted addressed the lesson previously learned.

It's also important to note that the process of continual improvement may not necessarily be a linear one. While some older models of continual improvement may have depicted it as a linear process, it is now better understood that the process may sometimes be iterative. For example, it may be necessary to go back a few steps and revalidate issues and root causes, if an implemented solution

- Does not actually solve the observed issue from the previous event, or
- Has unintended consequences.

The continual improvement cycle is described in Table 15.3.

Table 15.3: Continual improvement cycle

Phase	Purpose	Methods and Tools
Discovery	Collecting information, data, and feedback from an event (real or exercise) that can be used later to identify lessons to be learnt including areas of: strength, potential improvement, and potential best practices	• Sticky notes, pens, and whiteboards • Online "virtual whiteboards" or surveys • Conducting interviews with key personnel and stakeholders • Hotwashes
Validation	Analysing and validating the data collected during the discovery phase	• Data coding and analysis • After-Action Reviews • Peer reviews
Resolution	Finalizing, prioritizing, tracking, and implementing recommended courses of action and resolutions	• Leadership-driven prioritization • Cost- and/or feasibility-driven prioritization • Tracking spreadsheets or software
Evaluation	Transforming lessons identified into lessons learned; confirming that deficiencies have been corrected, processes have been improved, and/or best practices have been implemented.	• Subsequent event observation • Additional data collection and analysis

'Hot washes' and their typical significant discussion points

Organisations may elect to hold frequent "hot washes" to help support their data collection efforts. A hotwash is a quick, informal review of issues and ideas conducted during, or immediately after, a longer event, exercise or emergency. Its objective is to identify strengths and weaknesses of the response. Frequent hot washes increase situational awareness and provide improvement opportunities to correct deficiencies early on, particularly when conducted daily or at shift changes.

An example of some discussion points that might be included in a hot wash are:

- What happened/main outcomes from the event/exercise?
- What is/are the reason(s) for these outcomes?
- What worked well and not so well during the exercise?
- What would you improve?
- Were roles and responsibilities clearly understood? If not, where were the gaps?

Ideally, an organisation will have plenty of time to allow continual improvement processes to unfold before they are embroiled in response efforts for the next emergency. Indeed, there are many low-consequence, low-stress environments in which an organisation can facilitate knowledge sharing while also testing and evaluating implemented solutions and actions before a subsequent event. These methods, including training, exercises, professional development, and continuing education opportunities are discussed in greater detail in the next section.

15.3 Education, training and exercises

The role of professional education, training, and exercises is fundamental to knowledge sharing and organisational continual improvement. Lessons learned and knowledge sharing should be the foundation for professional development of emergency management and flood response professionals (Section 15.3.1) and training and exercises (Section 15.3.2) with them. This approach places context, practicality, and relevance at the forefront, all of which are key considerations in adult

learning (Lieb, 1991), thereby increasing the chance for true knowledge transfer and actual learning to occur, moving lessons observed into lessons learned.

15.3.1 Continuing professional education and development

Continuing professional education is vital for progress and affects both the professional and the organisation. Using lessons learned and case studies to develop professional education keeps professionals and organisations current, helps facilitate a shift to true learning organisations, and helps keep professional development aligned with the central tenets of adult learning.

Of course, one of the common hurdles to developing and/or delivering quality professional development opportunities for both organisations and individual professionals is time and cost. However, post-pandemic collaboration tools have proven to be extremely effective, just-in-time delivery methods for bite-sized professional development and continuing education opportunities.

Learning opportunity webinars (USACE)

In the United States Army Corps of Engineers (USACE) Emergency Management Community of Practice, twice-monthly virtual "lunch and learns" or 30-minute webinars have become a proven best practice in providing low-cost, high-impact professional development. Introduced in 2021, these virtual, interactive, synchronous sessions are used to promote and facilitate a knowledge-sharing and continual learning environment within the Community of Practice and are open to any USACE employee who may want to learn more about emergency management.

The twice-monthly format works exceptionally well when lessons learned during real-world events require immediate corrective actions and training updates, keeping the series relevant and useful for its intended audience. The sessions are also recorded for asynchronous use as well, and over time the library of webinar offerings has become an extremely cost-effective and efficient addition to the organisation's overall distance learning curriculum

15.3.2 Training and exercises

Using training and exercises is another excellent way to incorporate the continual improvement cycle into organisation culture, as recurrent scheduled events, or part of a more structured professional development curriculum.

Training exercises (USACE)

Collaborative flood response training and exercises with interagency and community partners are a regular feature in USACE's annual response and recovery cycle. For example, USACE provides annual flood response training in dozens of communities across the United States, including hands-on training on how to fill sandbags and operate automated sandbag filling machines, how to fill and use gabion baskets appropriately, as well as collaborative classroom training on understanding levee safety and flood risk management principles. Participants include local governments, State and Tribal governments, as well as other Federal agencies. Providing this annual training is a proven best practice that also provides a forum to implement recommended courses of action for issues identified during previous floods, transforming lessons identified into lessons learned for all partners.

Exercises are a powerful tool in an organisation's continual improvement toolbox, especially when they are specifically designed and developed to address identified gaps and issues observed during prior response and recovery events. For example, if an organisation observes a procedural or process error during response efforts, designing an exercise that specifically walks participants through the correct procedure or process can help transform a lesson observed into a lesson learned.

Exercises can also be used to test updates to training, plans, operating procedures, and policies that have been implemented as part of an organisation's continual improvement lifecycle. Exercises afford organisations a low-stakes environment to validate whether a specific solution implementation will truly solve a problem identified in earlier phases of continual improvement, or whether the root causes of a specific problem may need to be re-examined.

Finally, exercises can also be designed and developed around case studies, either from within an organisation or in partnership with an external stakeholder. This methodology allows exercise facilitators to compare participant response with the actual response during the historical emergency, using the gaps found between the two as teachable moments. This methodology permits learning from both the experience of individual participants as well as from shared history and partnerships. Exercises also build, sustain, and strengthen relationships. Ensuring the right participation in exercises and getting the right people in the room means organisations can learn broader lessons than just their own or the ones that they have identified previously.

Exercises should be formulated to include components that test both the organisation, its processes, and the individuals involved. To guide the selection of the most appropriate type of exercise (see e.g. Figure 15.3), the following should be defined in advance:

- What is the need/purpose and objectives for the exercise?
- What is the scope of the exercise?
- Who are the required participants (internal and external)?
- Who are the beneficiaries of the exercise (if more than just the participants)?
- How will it be evaluated?
- Where does it fit within other training processes and exercises?

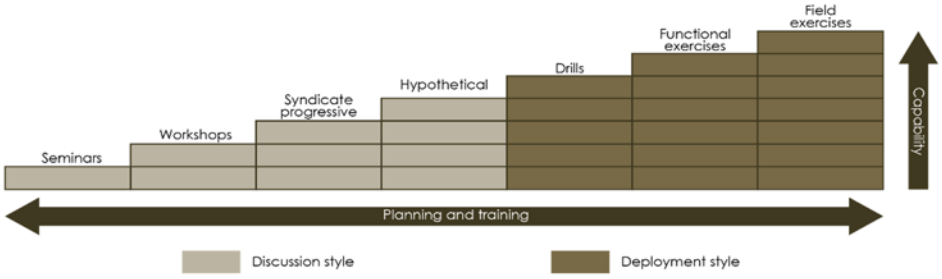

Figure 15.3: Types of exercises (from Australian Disaster Resilience Handbook Collection, Managing Exercises, AIDR, 2012)

Many of the types of exercise shown in Figure 15.3 will be familiar, but two types of exercise that merit explanation are:

- Syndicated Progressive. This exercise introduces problems that progressively increase in complexity as the exercise progresses and require a collective approach to solve. This type of situation commonly arises in emergency situations. The exercise thus tests the ability of members of the group to work effectively together and use each other's strengths as much as their individual technical knowledge.
- Hypothetical. This is typically a facilitated exercise where a panel of individuals are tested against a hypothetical event, often for the benefit of a wider audience. Unlike drills they may introduce issues well beyond those that might be expected for a given flood defence scheme. They may also (unlike drills) at times partially rewind the sequence of events in the emergency to test alternative response scenarios or pathways.

Every exercise should have an evaluator. More complex exercises may also benefit from having one or more observers.

- Evaluators will be assessing the performance of the exercise against a series of pre-defined questions, primarily linked to the purpose and objectives of the exercise. They will draw on a range of data collected during and after the exercise (e.g. feedback forms, hotwash etc.).
- Observers will typically focus on overall impressions, including how people responded and interacted with each other. Observers may include subject matter experts to provide insights in the organisation's maturity (Section 15.2.1) in each area of emergency preparedness.

15.4 Helping each other

15.4.1 Organising cross-boundary assistance

There are good examples of existing networks that seek to provide cross boundary assistance to those needing to manage flood events, either during the preparedness phase or the response phase. Such networks provide practical resources for organisations seeking assistance. The networks generally take account of the potential risks associated with external support with a simple set of rules; this is insightful and promotes responsible collaboration. Risks in seeking support from partners that may need to be considered include:

- Who is responsible for the support action undertaken by partners?
- Does the host organisation have time to house partner experts and provide their PPE (see Chapter 13)?
- How will health insurance for the visiting partner experts be provided?
- Will the media consider external help as a poor reflection of the flood risk experts from the host country?
- Will politician use the support provided for their own goals?

Figure 15.4: Practical exercise in Switzerland in 2019 for flash flood advisors (courtesy: Eric van Kuijk).

[European] Union Civil Protection Knowledge Network – a preparedness phase opportunity	
This is described as a "hub that connects first responders, disaster risk managers, scientists, and decision-makers and matches their needs for expertise and good practices with methodologies, tools, solutions, and resources". This network is intended for EU member states and EU participating states. Examples of training programmes within this network are given below:	
Programme	**Purpose**
Union Civil Protection Mechanism Training Programme	To strengthen cooperation and coordination among its Member and Participating States in the field of civil protection, the Union Civil Protection Mechanism (UCPM) offers a dynamic and comprehensive training programme tailored to specific target groups through its Knowledge Network. The UCPM Training Programme supplements the national training offered to experts and intervention teams by their home country or organisation to better prepare them for international deployments under the Union Civil Protection Mechanism.
Exchange of Experts Programme	The Exchange of Experts (EoE) programme involves connecting experts across borders to broaden their operational knowledge and skills through practical experiences in the field. The exchanges offer insight into the work of civil protection organisations and experts across Europe and beyond. Improving mutual understanding between teams working in different and challenging conditions reinforces civil protection knowledge at home. Participating in an exchange provides civil protection experts with valuable experiences and deeper knowledge, strengthening teams and their services.
Civil protection exercises	The exercise programme of the Knowledge Network offers a variety of civil protection exercises in order to enhance prevention, preparedness and disaster response (see example in Figure 15.4). It does so by ensuring compatibility and complementarity between the intervention teams deployed through Union Civil Protection Mechanism (UCPM) missions and other intervention support, improving the competences of the experts involved in the European civil protection system.

Response Phase Opportunities

EU Civil Protection Mechanism – a response phase opportunity

An example of a response phase opportunity is the EU Civil Protection Mechanism established in October 2001 by the European Commission. The Mechanism aims to strengthen cooperation between the EU countries and 10 participating states on civil protection to improve prevention, preparedness, and response to disasters.

When the scale of an emergency overwhelms the response capabilities of a country, it can request assistance. Through the Mechanism, the European Commission then can play a key role in coordinating the response to disasters in Europe, or to any other country or international organisation asking for help. As part of the Mechanism, the Emergency Response Coordination Centre (ERCC) monitors events around the globe 24/7 and ensures rapid deployment of emergency support through a direct link with national civil protection authorities. A range of specialised teams and equipment can be mobilised at short notice for deployments inside and outside Europe.

Incident management protocol between Dutch, English and USA governmental execution offices	
This Incident management protocol between Dutch, English and USA governmental execution offices has been set up under the umbrella of a Memorandum of Understanding. Participants are the Environment Agency (England), United States Army Corps (USACE) and Rijkswaterstaat (Netherlands). Under this protocol: • the observer is the organisation visiting the incident • the host is the organisation that is responsible for acting during the incident	
Part 1: General approach	
Item	**Content**
Confidentiality	The observer will keep confidential all information acquired or disclosed during any incident observation except where: • Such information is already publicly known or becomes generally available to the public (other than by any breach of this protocol). • The observer has already been provided with the information on a non-confidential basis. However, the observer may make use of any such information for: • The purpose of developing or enhancing its own procedures for, and approaches to, incident response. • Academic training or professional purposes (both internal and external) provided that (a) prior to such use the observer will provide the host with advance details of the information which they intend to use (including copies of any presentational materials) and (b) such information may be used by the observer only with the approval of the host.
Costs	The observer leads will cover all their own costs, including travel, accommodation and subsistence. They will not be reimbursed by the host in any way.
Roles and governance	MoU lead contacts will work with their organisations to identify host leads and observer leads and buddy these staff members up. Once a host lead has been buddied with an observer lead communication will take place directly between them. Executive level governance will be through the MoU Steering group. The work will be monitored by the MoU lead contacts.
Health & Safety	Observer leads must be trained in their own Health and Safety policies. Observer leads will be briefed by host leads on all relevant host Health and Safety policies/ Operational Instructions and will be responsible for ensuring they comply with these. Observer and host leads will agree who will provide any necessary items of PPE (hi vis jackets, steel toe caps, hard hats etc.) Considerations will include: • Desired branding/logos – observer kit shows observer logo, host kit shows host logo. • Travel practicalities – what can easily be taken on the plane
	Observer leads will be accompanied by a host member of staff at all times when observing a host incident response. The nominated geotechnical specialist in the field is responsible for determining risks for instability or otherwise that might endanger the situation for new breaches or personal safety of team members.
Part 2: Specific actions at each stage	
Item	**Content**
Joint Preparation for incident observation (step 1a)	The host lead and observer lead will be responsible for completing the preparation phase together. This is likely to include the following activities: • Understand each other's incident management approach. • Understand H&S requirements, PPE needs, etc. • Hold face to face meeting & incident room familiarisation. • Agree learning topics & feedback framework and mechanism. • Agree logistics – travel approvals, airports, transfer, accommodation, building access, contact details.
Host preparation for incident observation (step 1b)	Host MoU lead contact will work with host leads to ensure appropriate communication is shared with host incident management community to enable the observer observation.
Initiating the incident observation (step 2)	Host leads will work with the relevant National Duty Manager (NDM) and/or Area Duty Manager (ADM) at the start of an incident to agree whether an observer lead can be invited and any internal communications requirements. This includes consulting with the wider group of host leads. Host leads will be responsible for inviting observer lead(s) and will keep MoU leads informed on the details of agreed observations. Observer leads will arrange all their own transport, travel and accommodation. If they choose to use the EU exchange of experts mechanism, the host will support this.
Incident observation (step 3)	Host leads will be responsible for the observer lead, ensuring they are accompanied at all times when in the incident room/on-site. Observer leads will be sensitive to the operational pressures and demands on the host in their incident role and will ensure their presence doesn't impact the host response. All media and social media activity relating to the incident observation must be approved by the host national newsdesk: e.g. newsdesk@environment-agency.gov.uk
Incident feedback (step 4)	The observer lead will provide feedback on their incident observations as agreed during the preparation phase. Hosts will debrief the steering group on the feedback they receive and proposed next steps. All media and social media activity relating to the incident feedback needs to be approved by the host national newsdesk: e.g. newsdesk@environment-agency.gov.uk

15.4.2 Cultural awareness and building trust

In a mission, the situation is often complicated by the interaction of diverse organisational and national cultures. Missions bring heterogeneous personnel into contact with local people who often draw upon cultural backgrounds different from those of the operation and its staff. The potential for culturally based misunderstandings and conflicts is thereby increased. That is why it is important to be aware of the different cultures and how to deal with them.

Definition and explanation of culture

Culture is the shared characteristics of a group of people, which encompasses place of birth, religion, language, cuisine, social behaviours, art, literature, and music. Some cultures are widespread and have a large number of people who associate themselves with those particular values, beliefs, and origins. Others are relatively small, with only a small number of people who associate themselves with that culture. However, the value of culture cannot be defined by its size. No matter if a culture is widespread or kept within a small region, is young or old, or has changed over time or stayed the same, every culture can teach us about ourselves, others, and the global community.

Source: National Geographic.org, Cultural Identity

Types of culture and issues with cross-cultural interactions

The several hundred national and regional cultures of the world can be roughly classified into three groups:

- Task-oriented, highly organized planners (linear-active);
- People-oriented, loquacious inter-relators (multi-active);
- Introverted, respect-oriented listeners (reactive).

There are various levels of difficulty in interacting between these groups (see Figure 15.5) A person from a people-oriented culture may see someone from a task-oriented culture as inflexible and time-dominated. In comparison a person from a task-oriented culture may see someone from a people-oriented culture as chaotic and unstructured. The person from the respect-orientated culture will sit back and try and quietly learn from both.

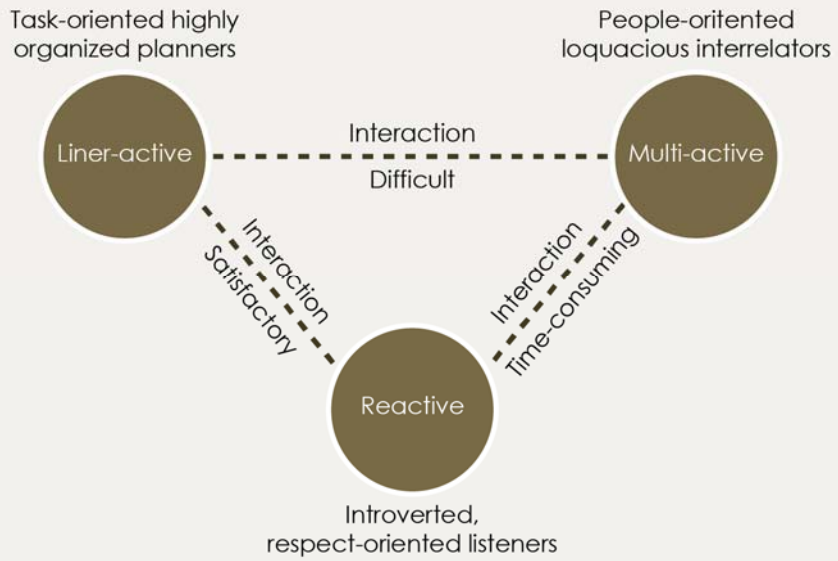

Figure 15.5: Levels of difficulty in LMR Interactions (after Lewis, 1996)

When people from a linear-active culture work together with people from a multi-active culture, irritation results on both sides. Unless one party adapts to the other, and they rarely do, constant crises will occur. For example, the person from a linear active culture might ask,

- Why don't they ever arrive on time?
- Why don't they work to deadlines?
- Why don't they follow a plan?"

While in return the person from the multi active culture asks,

- Why keep to the plan when circumstances have changed?

- Why keep to a deadline if we rush production and lose quality?

However, such differences may eventually be resolved, when for example:

- the 'reactive' person accepts that the 'linear active' person's directness is, after all, just being honest.
- the 'linear active' person perceives that exaggerated 'reactive' person's courtesy is, after all, better than hostility.
- the 'multi-active' person talks 90 percent of the time in conversation with a 'reactive' person, who is content to be silent, both then being happy and doing what they do best.

Working in a different culture or organisational system clearly is beneficial to individual flood defence emergency workers, providing wider horizons and a diversity of views and approaches. Differences between individual team members from different cultures will depend mainly on their personal talents, education and experience, but members of international teams also often display traits that derive from the characteristics of their national culture which can add value to a team if appropriately harnessed. Examples of the advantages of a diversity of character traits in teams are given in Table 15.4.

Table 15.4: Advantages of diversity traits in a team (Lewis ,1996)

Trait	Benefit / Strength
Versatility in Problem Solving	• Generates more alternatives. • Responds better to cultural preferences in local markets. • Better local forecasting. • Better critical analysis.
Creativity	• Broader perspectives, less emphasis on conformity. • Better product design.
Diversity in General	• Not only "black" and "white" but also "both-and". • Not only "one-way" assumptions. • Asians, Africans and women have different cognitive styles. • Bilinguals have higher level of divergent thinking. • More charisma, stimulation and real dialogue. • Better tolerance with ambiguity and chaos. • Diverse talent compensates for inability to attract top local talent. • Sound moral basis. • Demographic trends indicate that in the second half of the twenty-first century, most of the workforce will be non-Western, non-white, non-male.

Empathy

Whilst diversity can be beneficial, a team can only gain value from it if team members have empathy for one another. Empathy is based on accepting differences and building on these in a positive manner. The emphasis on empathy and understanding cultural differences is crucial for successful international collaboration. The characteristics associated with empathy (Lewis, 1996) provide a valuable framework for developing cross-cultural awareness.

Characteristics of empathy (Lewis, 1996)

- Tact
- Sensitivity
- Compromise
- Calm
- Patience
- Observation of the other side's protocol
- Careful listening
- Inspiration of trust
- Humor
- Flexibility
- Politeness
- Warmth
- Willingness to clarify objectives
- Care to avoid irritants
- Respect of confidentiality
- Constantly trying to see things from the other's (cultural) point of view

The largely cross-cultural behaviours and actions listed in Table 15.5 may be helpful for creating a trusting atmosphere. However, because of cultural differences, it is recommended to check out the Do's and Don'ts for each country using information from the internet (see also Lewis, 1996).

Table 15.5: Behaviours and actions to build trust

Do	Do Not
• Tell the truth. • Be honest. • Exercise integrity. • Let people know where you stand. • Use simple language	• Manipulate or spin the truth. • Leave false impressions.
• Demonstrate respect. • Note the importance of little things. • Genuinely care. • Treat people with dignity. • Take time. Listen.	
• Create transparency	
• Correct mistakes. • Apologize quickly. • Demonstrate humility	
• Deliver results. • Establish a track record of getting the right things done. • Make things happen.	• Over-promise and under-deliver.
• Commit to continual improvement. • Be a learner. • Develop feedback mechanisms. • Act on feedback and appreciate it.	• Ignore or discount feedback
• Clarify expectations. • Disclose expectations. • Discuss them and validate them. • Be realistic.	• Create expectations that you will not be able to meet. • Assume that expectations are shared or clear.
• Listen before you speak. • Understand. • Listen with your ears, eyes and heart. • Ask them. • Demonstrate understanding and compassion.	• Presume that you have all the answers. • Presume that you know what is best for others.

15.5 Progressing innovations

Collaboration also provides an opportunity for innovation. Field laboratories and living laboratories ('Living Labs') support and stimulate the generation and exchange of knowledge and learnings on flood defence. Such laboratories offer realistic yet safe and controlled environments to experiment and test flood defence innovations in the actual water system. They can also be used to inform and train a flood defence emergency management team on how to adequately respond to an actual emergency.

Field laboratories are more focused on technical ingenuity and/or the manufacturability of products. Living labs by comparison focus more on testing the day-to-day use of the product and the needs of the intended users. In this way, they offer involvement with the real world and real people, and with that they carry a high social component. The innovation benefits of a living lab include:

- Interdisciplinary collaboration.
- Enabling interaction and events.
- Knowledge transfer between various stakeholders and students.
- Data collection and data analysis through research.
- A space for innovation and prototyping.

Living Labs

"Living labs are a new way of developing and applying knowledge. Living labs involve all the different parties required for identifying solutions to social issues. It is not just about technical progress, but also about social innovation. We often see multiple problems come together, and living labs are a particularly suitable tool for addressing these types of complex problems" (Deuten & Slump, 2018).

Another important aspect of living labs and field labs is that, besides their main objective of progressing innovations, they can also be used as a team training ground for flood defence emergency management

organisation to prepare for emergencies. The following advantages of such labs can be identified for an emergency management team:

- They can learn how to install and operate innovative temporary flood defences during flooding events in a controlled environment.
- They can develop soft skills such as leadership, communication and adaptability and learn to apply them in stressful situations.

All the lessons learned from training in a realistic flooding situation enable an emergency management team to be better prepared for the moment when a real flood defence emergency occurs.

Flood proof Holland

The devastating floods in Limburg reaffirmed the need of adequate flood defence in hilly areas and thus the necessity to update skills and knowledge on flood defence. Therefore, an area on the TU Delft campus was transformed into a field laboratory for innovative flood defences for use in flat polder areas. This open air laboratory, called Flood Proof Holland, consists of various open-air basins, in which temporary, modular, and flexible flood defences can be built. In each basin, floods can be simulated to test the strength of the flood defence. Obstacles can be placed to simulate urban situations. There is also a test dike on which multiple experiments have been carried out (e.g. piping and breach tests).

Of relevance to emergency management of flood defences, semi-full scale temporary innovative modular and flexible flood defences were tested and optimized to improve their reliability. Examples of flood defences tested include:

- The Tube Barrier (Figure 15.6a), designed to provide a long length of protection close to a water source. When flood water arrives at the barrier, the inlet openings at the front of the tube allow water to flow inside. Eventually, the water inside balances the outside water level, stabilizing the system.
- The H-Wall barrier (Figure 15.6b) a rigid free-standing barrier. It comprises of three components: the single rigid element, tension straps, and wrapping membrane. For stability, the weight of water over the front leading edge and the tension straps will support the whole barrier. The combination of wrapping membrane and sandbags prevent water from flowing underneath the barrier.

a

b

Figure 15.6a: Tube Barrier under test at TU Delft (courtesy: Robèrt Kroonen)
Figure 15.6b: H-Wall under test at TU Delft (courtesy: Robèrt Kroonen)

The Field Lab of Flood Proof Holland provided the opportunity for entrepreneurs, research and students, to conduct tests on these temporary barriers. During these tests, the barriers were evaluated on their stability, durability, watertightness, and resistance to longitudinal flow as well as overtopping. The addition of a tracer fluid (Figure 15.7) during these tests allowed leakage problems to be identified. The lessons learned during the testing at Flood Proof Holland facilitated further technical development of these temporary flood defence innovations and also inspired regional water authorities to conduct similar experiments in their own areas (such as the field tests in the so-called de Groene Rivier). The tests also provided opportunities for:

- Groups of workers (e.g. soldiers – See Figure 15.8) with different levels of experience to install the temporary defences and the effectiveness (see Chapter 14) of their installation to be tested.
- Remote observation of the effectiveness of the temporary defences using 5G-supported webcams (see Figure 15.9) Using 5G enabled the team to observe the barrier in real time and act as rapidly as possible in the event of failure.

Figure 15.7: Test with tracer fluid at Flood Proof Holland together with Regional Water Authority Limburg, The Netherlands (courtesy: TU Delft)

Figure 15.8: Training together with multiple stakeholders (The Netherlands) (courtesy: TU Delft)

Figure 15.9: Researchers observe the effectiveness of a barrier using 5G-supported webcams (source: USACE)

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CHAPTER 16

Justifying the required funding

Key messages:

- **Use multiple approaches to justify funding**
- **Aspire to multi-year and reserve funding**
- **Prioritise activities with the largest benefits**

Figure 16.1: Structure of the handbook

Other places to find information on the topics of this chapter

Chapter 2: high level overview, showing how funding is organised institutionally

Chapter 3: funding of resources and capabilities needed in the preparedness phase

Chapter 4: funding of resources and capabilities needed in the response phase

Chapter 7: understanding of the resources and capabilities needed for crisis communication

Chapters 8 through 12: understanding of the process and what resources and capabilities need to be in place

Chapter 13: understanding resources and capabilities of health, safety and wellbeing that need to be in place

Chapter 14: understanding reliability analyses and what this means for setting priorities in funding

Chapter 15: understanding the resources and capabilities needed for education, training and exercises

Chapter 17: guidance on how to make the handbook work for you and what steps are needed to take your organisation to the next level

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Note:

The Reader is kindly requested to take note of the Disclaimer on page ii of this handbook.

Chapter title page photograph:

Much needed funds (courtesy: Eric Huijskes)

Key messages:

- **Use multiple approaches to justify funding**. The benefits of investments in flood preparedness and response resources and capabilities in most cases significantly exceed their costs. As benefits of preparedness and response are generally difficult to quantify, different approaches to quantifying benefit streams and justifying resources and capabilities should be pursued in parallel to provide sufficient confidence among the decision makers.
- **Aspire to multi-year budgeting and reserve funding**. The flood defence manager should aspire to have (i) multi-annual budgeting and (ii) an additional emergency fund in place should one or multiple event(s) exceed available resources and capabilities.
- **Prioritise activities with the largest net benefits**. Given limitations in available funds, prioritise chains of preparedness and response activities that ultimately result in the largest net benefits.

This chapter focuses on the justification of funding of resources and capabilities needed for emergency management of flood defences. The scope is therefore limited. General flood emergency preparedness and response and multi-hazard emergency preparedness and response have much larger scopes. Chapter 2 describes the wide range of organisations that play a role here and explains the roles and responsibilities of those involved. Given this complexity, in this chapter we will focus on the resources and capabilities required by the flood defence manager or their equivalent, related to emergency preparedness and response for flood defences that fail or threaten to fail.

Justification of funding almost always relies on quantification of benefits. For this reason, benefits are often quantified in monetary terms (e.g. reduced Expected Annual Damages) or in terms of saved lives (e.g. reduced Expected Annual Fatalities). The benefits of preparedness and response in emergency management of flood defences are broad:

- Saving of lives and enhancement of public safety.
- Minimisation of economic, natural capital and property damage.
- Increased resilience (effective response can help faster recovery).
- Reduced stress and trauma.
- Enhanced public trust and hence more effective response.

Additional benefits arise when the various resources and capabilities can also be used for managing non-flood hazards. Examples include pumps that can also be used for firefighting and vehicles which can also be used for evacuation during earthquakes. Because of the complexity of benefits, when justifying the resources and capabilities, multiple or parallel justification approaches should be considered; using more than one approach is likely to increase confidence of those that need to take the decisions to allocate funds and invest.

Given this context, this chapter includes the following:

- Section 16.1 sets out the main components of resource and capability that might require funding justification.
- Section 16.2 explains how the funding is typically organized to provide these resources and capabilities.
- Section 16.3 describes methodologies that can be used to justify expenditure on preparedness and response measures for emergency management of flood defences, including benefit costs analysis, cost effectiveness analysis, multi-criteria analysis and various types of benchmarking.
- Section 16.4 discusses how best to prioritise investments, where (as is common) the actual funding levels provided are less than ideal.

16.1 Resource and capability components

In this section, the various components requiring funding for emergency management of flood defences are presented. A distinction is made between resources and capabilities that are needed before, during and after a flood. Some of the resources and capabilities presented in this section extend beyond emergency management of flood defences; this is not untypical, because funding is frequently sought for holistic packages of flood risk management activities.

Table 16.1 shows an overview of typical items that require funding. We recognise that the items listed in the table can be seen as the ideal situation to be aspired to, but rarely fully achieved. Typical costs of what is required are not given as there is too much variability. The call out boxes below illustrate a few of the items in Table 16.1 with a reference (see A, B, C, D, E and F) which refers to the corresponding letter in Table 16.1.

Table 16.1: Overview of resources and capabilities for management of flood emergencies that require funding

Phase	Before the flood				During the flood	After the flood
	General preparation	**Early Warning**	**Inspections**	**Readily available response**	**Preparation / mobilization / implementation**	**Recovery**
Resources & Capabilities needed	• Offices • Staff • Policies • Plans • Education, training, exercises • Hazard & risk maps (A) • Asset information (systems) (B) • Research & Development programmes (C)	• Meteorological stations and services (D) • Water level gauges • Sensors • Forecasting systems • Warning systems • Communication systems • Staff	• Routine inspections • Event inspections • Decision support systems • Staff • Volunteers (E) • Personal Protective Equipment (PPE)	• Warehouses • Response centres • Equipment (store, maintain and repair) • Staff • Volunteers (E) • Contractors (F) • Personal Protective Equipment (PPE)	Implement response, i.e. mobilise and implement equipment, i.e.: • Retaining barriers (e.g. mobile barriers, inflatables, big bags, sandbags) • Stabilising (e.g. big bags, sandbags, earth, rock, etc) • Water level lowering (e.g. pumps, diversions) • Transportation and access (e.g. vehicles, trucks, loaders, boats) • Clearing and access (e.g. bulldozers, excavators) • Communication • Ancillary equipment (e.g. generators) Other: • Staff • Volunteers (E) • Contractors (F) • Personal Protective Equipment (PPE)	Continued use of equipment, in particular (see also "during flood"): • Removal of water • Transportation • Clearing • Communication • Ancillary (e.g. generators) Repairs and build-back-better: • Earthworks • Rock, revetments • Concrete works • Sheet piling Relief & aid: • Emergency shelters and basic necessities • Disaster relief supplies (blankets, clothing, etc) • Health services • Emotional support Other: • Staff • Volunteers (E) • Contractors (F) • Personal Protective Equipment (PPE)
Purposes served	Mainly flood, but can be multi-hazard	Multi-hazard	Flood related	Multi-hazard	Multi-hazard	Multi-hazard
Who to fund	• Flood Asset Manager	• Flood Asset Manager • Other beneficiaries for other hazards	• Flood Asset Manager	• Flood Asset Manager • Other beneficiaries of equipment for other hazards	• Flood Asset Manager • Other beneficiaries of equipment for other hazards	• Flood Asset Manager • Other, e.g. relief and aid generally provided by other entities with support of NGO's

Justifying needs identified by flood mapping (items A in Table 16.1) for the EU Flood Directive

Every six years member states are required by the EU Flood Directive (2007) to carry out Preliminary Flood Risk Assessments, identifying Areas of Potential Significant Flood Risk (APSFRs). For each of these APSFRs subsequently flood hazard and flood risk maps need to be produced and a program of measures needs to be defined and reported in Flood Risk Management Plans. This program of measures typically will also highlight needed and prioritised preparedness and response resources and capabilities. These typically need to be justified through e.g. benefit-cost analysis (see Section 16.3).

In Romania (2023), following the production of hazard and risk maps, about 300 person-days of work was needed to identify current resources and capabilities, carry out a needs assessment and subsequently justify the funding of an all-round preparedness and response package for the entire country. The resulting report was an essential step to attract EU funds for implementing the package.

Asset information systems (items B in Table 16.1) help identify "Top 10" vulnerable defence locations

A characteristic of the Netherlands primary flood defences is the high standards of protection that are adhered to. Linked to this. there is also a strong emphasis on inspections of flood defences, because failure of a defence would have catastrophic consequences. Since 2008, triggered by Hurricane Katrina in the USA, there has also been a more pronounced drive to plan emergency response and to be able to execute the plan.

As part of preparedness, the Regional Water Authority Drents Overijsselse Delta decided to identify their "top 10" vulnerable locations based on likelihood of failure. These were locations at which the flood defence were likely to need "strengthening" because they did not meet the legally required standard of protection. Using their asset management information system, an inventory was carried out and hotspots were identified and documented, together with a proposed plan of action should extreme water levels occur. The process also triggered the setting aside of sufficient equipment and resources to successfully implement the potential needed response.

This straightforward planning exercise, funded internally by the Regional Water Authority itself, can be seen as a low-cost preparedness activity that could be undertaken in any country to assess needs.

Research & Development (items C in Table 16.1) programme Polder 2Cs used to enhance resources and capabilities

As part of INTERREG, the European Regional Development Fund, partners from Netherlands, Belgium, France, UK and USA attracted research funds focusing on the following four research and knowledge sharing areas:

- Flood Defence - carry out research on the strength of flood defences.
- Emergency Response - design new and better emergency response plans.
- Knowledge Infrastructure - formalise knowledge transfer and educate the next generation of water managers.
- Realisation of a field station, to allow full scale testing of developed approaches and theories.

The project website https://polder2cs.eu/ gives details of the preparedness and response concepts developed. The overall budget was € 6 million over a period of 4 years, making it possible for the partner organisations to enhance their resources and capabilities.

National Meteorological and Hydrological Services (NMHSs) (items D in Table 16.1)

According to Rogers and Tsirkunov (2013), nearly all governments accept full responsibility for funding the operation of their NMHSs. These can be seen as an essential component of the national taxpayer-funded government infrastructure, together with for example police, army and national radio. Obviously NMHSs remits go beyond that related to floods. The benefits of NMHSs go far beyond the scope of this handbook, typically

impacting all households (response planning), transport sector (safety, efficiency and reliability) and of course water and flood risk management (e.g., maximizing agricultural and hydropower output, minimizing flood losses and damages).

In developing countries, there is often a funding gap for these services. Historically this gap has partly been filled through approaches such as incremental fees for user-specific services, industry-specific taxation measures, or direct percentage-based contributions.

Making use of volunteers as a powerful resource (items E in Table 16.1

In the Netherlands major floods are quite rare. Primary flood defences have been designed to meet high standards of protection. Nevertheless, preparedness and response are an important part of the overall approach to flood risk management. For Dutch flood asset managers, such as the Regional Water Authority Drents Overijsselse Delta (WDOD), if a flood emergency were to occur, they would be highly understaffed. To employ sufficient staff does not make sense as they would be idle most of the time. To address this, WDOD has mobilised two volunteer work forces:

- The High Water Brigade: includes some 270 volunteers that will operate demountable and temporary flood defences in the cities of Kampen and Zwolle.
- The Inspection Brigade: includes some 800 volunteers that assist in flood defence inspections during (potential) flood events.

Both volunteer groups are trained annually and are involved in annual exercises. The reward for the volunteers lies in being part of the community that carries out these tasks, supported by passionate professionals, as well as clothing to safely carry out the work and sharing great meals during the training and exercises, including the famous meatball with gravy (see Figure 16.2).

Figure 16.2: Well deserved dinner after an exercise

Cooperation with private sector construction contractors (items F in Table 16.1)

In Japan, local construction companies have many civil engineers, equipment including heavy machinery, and knowledge of local natural/social conditions, and can make a significant contribution to flood defence related activities.

Therefore, the flood defence managers and the construction industry association consisting of many construction companies have signed agreements as to how and when services are provided. Various construction companies have been dispatched to support flood defence activities during emergencies at the request of the flood defence managers.

This system is also beneficial to the construction companies, as not only are they paid for their contribution (see for example Figure 16.3), but also receive an award that is used by the Japanese government as an advantageous score in upcoming construction tenders.

Figure 16.3: contribution by a construction company at a flood event in 2019 (pumping inland water to a nearby river) (source: MIE Prefecture Constructors association, Japan)

16.2 Organisation of funding

The organization of funding and the institutionalisation of funding mechanisms for preparedness and response varies from organisation to organisation and from country to country. As shown in Table 16.1, various items have multiple beneficiaries. Investments in, and maintenance of, such items are generally shared among different organizations. In many countries, for example, various components of the emergency response resources and capabilities are also required by the Ministry of Interior (or equivalent) and hence they too will (partly) fund such needs.

In an ideal world – rarely achieved but a sensible goal – the flood defence manager should have in place:

- Multi-annual budgeting, based on a medium to long term vision of risks, to ensure all preparedness activities can be funded.
- An additional reserve fund should an event or events exceed existing standards of protection.

To arrive at such multi-annual budgets, the flood defence manager should:

- Set up clear institutional arrangements, from policy to planning, to organizing all operational activities, including for example education, training and exercises.
- Institutionalise the Plan-Do-Check-Act cycle and ensure likely subsequent needs are economically planned for.
- Monitor and evaluate spend systematically, whether on a monthly, quarterly or annual basis.
- Have identified sources of funding and mechanisms to attract these in a timely manner.
- Have clearly distinguished between longer-term capital investments (e.g. a forecasting & warning centre) and year-by-year revenue expenditure (annual running costs).

In practice, many organisations and countries are not able to work systematically towards this long-term goal. Budgeting is likely to be more piecemeal and justification for funding may be challenged by many other (non-flood related) priorities. In such situations, the priority is to ensure that the basic resources and capabilities are available if there is a need to respond. This is addressed in Section 16.4.

Various categories of funding can be identified (Browder et al, 2021):

- Internal budgets (e.g. budgets through the tax / levy raising power of the organisation concerned, or budgets as part of the organisations operations).
- Loans (e.g. World Bank, EBRD, but also investment banks in the various countries themselves; generally used for capital investments or as recovery loans).
- Grants / subsidies (e.g. R&D stimulation funds, EU co-operation funds).
- Other (e.g. charity, donations by NGO's, crowd sourcing).

Cat DDO – a form of recovery loan

In 2018 the World Bank introduced a new financing mechanism (The World Bank, 2018) – the Development Policy Loan with a Catastrophe Deferred Drawdown Option (Cat DDO). This is a contingent financing line that provides immediate liquidity to countries to address shocks related to natural disasters and/or health-related events. It serves as early financing while funds from other sources such as bilateral aid or reconstruction loans are being mobilized. To qualify for this, the recipient must:

(i) Have an adequate macroeconomic policy framework; and

(ii) Be preparing, or already have, a satisfactory disaster risk management program, which the World Bank will monitor on a periodic basis. (Taking steps to improve the preparedness and response resources and capabilities will therefore enhance the potential to qualify for Cat DDO.)

Funding arrangements for flood risk management in the Netherlands

Flood risk management in the Netherlands is funded by the national government (74%), provincial government (4%) and the regional water authorities (22%). In 2013 this amounted to approximately €1.2 billion (Twijnstra et al., 2015). This equates to roughly is about 0.1 % of the GDP. More than 80% of this is covered by taxes and levies paid by citizens. The remainder is through taxes and levies provided by private sector, industries and agriculture.

Responsibility for allocating budgets for emergency response for flood defences falls to the national government (i.e., Rijkswaterstaat, the national water authority for public works and water management) and the regional water authorities. In view of the high to very high standards for primary flood defences, only a few percent of the overall budget is allocated to preparedness for emergency response.

In the case of flood events, two routes are available for damage compensation: the National Act for disaster compensation (Wet tegemoetkoming schade bij rampen) and insurance. The process is complicated, but experience with the Limburg summer floods of 2021 show that of the €1.8 billion damages nearly all compensation was paid out within one year of the event.

Dutch governmental institutions like Rijkswaterstaat and the regional water authorities also bid annually for EU grants and subsidies. This includes seeking funding for projects aimed at regional co-operation (e.g. INTERREG) or research (e.g. Horizon 2020, Copernicus).

Funding arrangements for flood event response in Japan

Almost all flood response is financed out of national or local government budgets. These budgets are secured every year through tough negotiations between the flood response authorities and the financial authorities of the governments.

In these negotiations, maintaining public awareness of the required flood response is important, since the budget that the financial authorities will allocate is covered by taxes. The flood response authorities therefore share and explain to the public and to the media information about flood response measures that have been implemented and their associated benefits. For example, after heavy annual rainfall events, the authorities immediately publicise information (reliable figures and attractive photos) about the floods and flood responses implemented at that time, such as the status of river levels, the operation of dams, gates and pumping stations, flood fighting activities. Whilst such communication efforts may not be rewarded in the short term, over a long period of time and with sincere commitment, they have built strong public support for implementation and investment in flood response.

Funding arrangements for preparedness/response in Mozambique

- At a national level the INGD (National Institute of Disaster Risk Management and Reduction) plays a key role in managing emergencies including floods. The Institute is governed by protocols that outline its tasks and responsibilities regarding for example early warning as well as coordination and follow up on response.
- At a local level, Disaster Management Committees carry out and coordinate emergency preparedness and response actions. Large cities like Beira have some 30 of such local committees. However Governmental funds at local level are limited, with a city like Beira having only several tens of thousands of dollars per annum.
- General maintenance and operation of water infrastructure is undertaken by the local authority. For example, the SASB (Beira Autonomous Sanitation Unit) is responsible for sanitation and water management and is responsible for maintaining waterways and clearing vegetation and debris.

In practice, maintenance and inspections of flood defences are (largely) lacking. Funds are provided generally for new investments, following events (e.g. Cyclone Idai in 2019). In such cases funds are provided by e.g. the United Nations, but these mainly target more general recovery needs. NGOs such as Red Cross/ Red Crescent also provide funds (several million dollars per annum), again generally targeting general needs, including shelters and evacuation planning. Funds at local level for preparedness and emergency management are therefore very small. At national level, the INGD is kept staffed and operational, but its effectiveness is limited given that there is little regional and local follow-up.

16.3 Justifying preparedness and response

In Section 16.2, various items were identified that need to be undertaken or to be put in place; these first need to be budgeted and then funded. Budgeting and funding occur at various moments in time:

- **Regular funding cycles**. These may be annual to ensure all resources and capabilities are in place for that given year, but also at dedicated moments in time when for example new investments are needed. In Europe, the EU Floods Directive (2007) cycles trigger revisiting needs assessment and planning every six years.
- **Emergency funding.** Flood events also often trigger new investments. In such cases, post disaster needs assessments (PDNA) are carried out that literally identify needs and provide recommendations on the way forward. Although generally the emphasis in PDNAs is aimed at restoring the general socio-economic situation and ensuring that basic needs (e.g. food, drink, shelter) are quickly met, PDNAs often also highlight needs regarding preparedness for future events (as in the USA).

In all cases regarding preparedness and response, both the need should be established, and the costs and benefits assessed. Once the need is clear and the benefits outweigh the costs, an investment can be justified and will encourage, for example, a flood defence manager to decide to progress that item.

A more pragmatic approach is taken in many countries such as the Netherlands, England and Japan, where justification of investments and expenditure can be based on softer grounds: the perceived need and the fact that emergency response is an important part of the flood risk management strategy may be sufficient. Nevertheless, in some cases (e.g. to attract EU funding in Europe, to attract funds from banks) more effort is required to justify needs.

In the following we will therefore elaborate on how justification can be made more specific and tangible if funders require this.

Justification of investments and expenditure related to the implementation, operation and maintenance of the items listed in Table 16.1 is complex for various reasons. These reasons include:

- Other preparedness and response tasks and responsibilities play a role. The scope of this handbook is quite limited (i.e. only in relation to flood defences) and hence there are also other tasks and

responsibilities (and hence benefits) that need to be considered (e.g. preparedness and response related to critical infrastructure such as hospitals).

- Other hazards play a role. in this handbook the focus is on flooding, however the items needed for preparedness and response can also be used to combat other hazards (e.g. fire, drought), yielding additional benefits.
- Other partners are involved. The flood defence manager does not work in isolation and relies on other partners to carry out its tasks and fulfil its responsibilities (e.g. they need inputs from meteorological institutes to forecast what may happen at their defences, other organisations may also have suitable equipment, such as pumps).
- The items involved are both diverse and interlinked and, in many cases, it is difficult to ring-fence the associated benefits linked to a specific item. Numerous items have a high interdependency or are even inextricably linked to other items (e.g. you need a warning before you can respond), thus justification can only be done if done integrally or when looking at sub-package level.

Benefit Pathways approach (Environment Agency, 2015)

The Benefit Pathways approach is widely used in the UK to assess both the baseline as well as "with package" situations. The approach analyses the chain of activities that ultimately result in a potential benefit, in this case:

Monitoring → Forecast → Warning → Response / Rescue & Relief → Benefit

By systematically analysing this chain, including associated probabilities of successful implementation, the benefit can be derived. In the high level example provided by the Environment Agency (2015 - see Figure 16.4), the relevant pathways for a flood defence manager are mainly "water course management" and "operation of active flood defences". No doubt this would require more detailing to arrive at a benefit assessment that is relevant to the remit of this handbook.

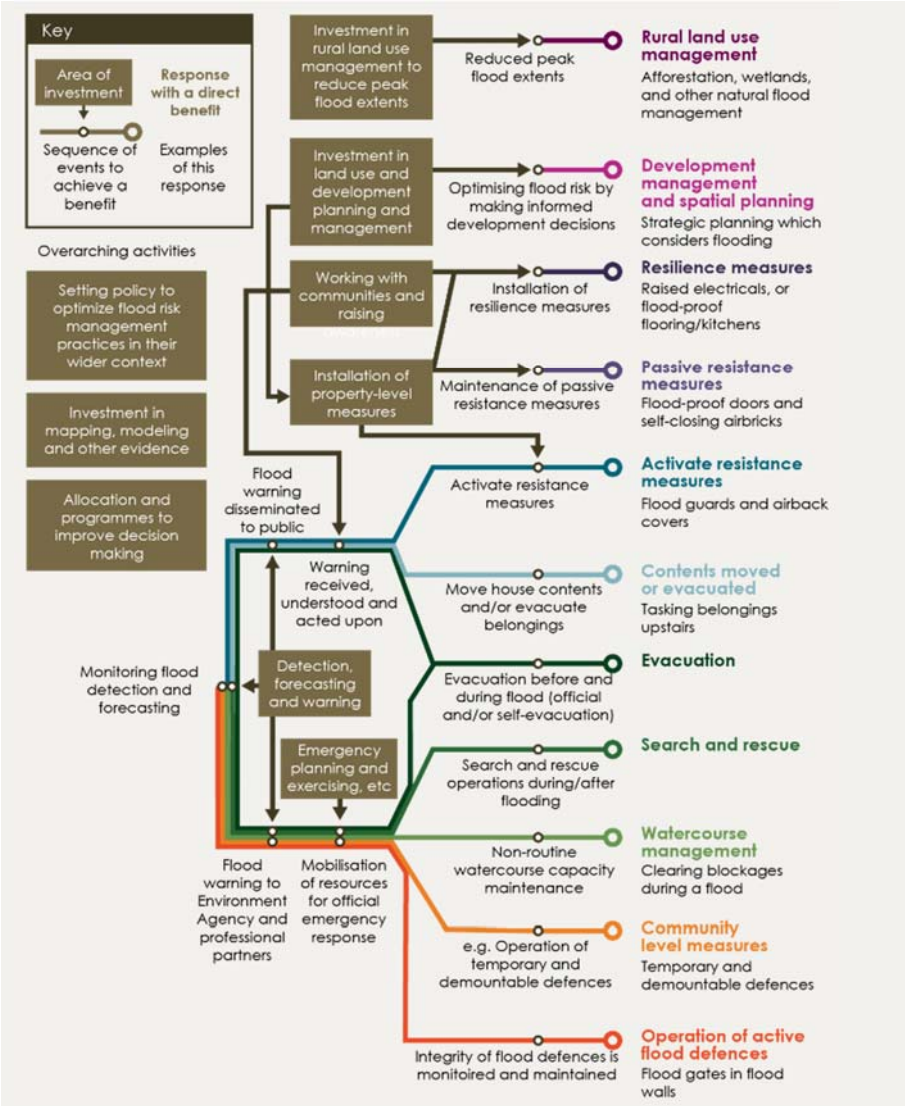

Figure 16.4: Benefits Pathway assessment framework for flood risk management (Environment Agency, 2015)

Despite difficulties in justifying resources and capabilities, the key decision makers may still need some form of justification. Various approaches are available and may be used in parallel, such that a decision can be taken with maximum confidence. When selecting the approach to justify funding, the decision tree shown in Figure 16.5, inspired by both UNFCCC (2011) and Doczi & Ross (2014), may be used. The resulting justification approaches are discussed in subsections 16.3.1. to 16.3.3 which follow.

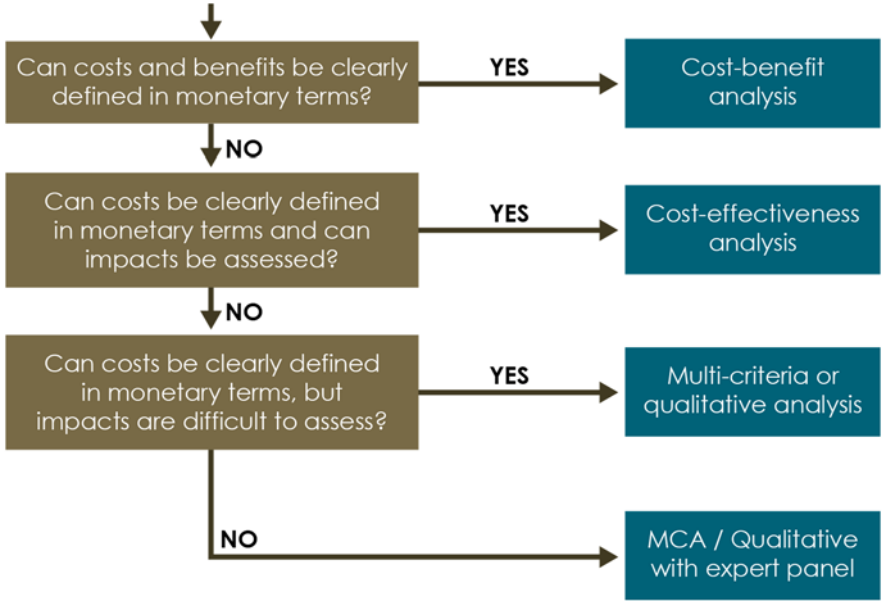

Figure 16.5: Decision tree to define justification approach

When moving through the decision tree, the decision on the selected approach may not be completely clear cut and so parallel approaches to justification may be considered. This can be useful and reasonable, provided the underlying caveats and assumptions are clearly stated, so that decision making can be undertaken transparently. Multiple or parallel approaches can help instil confidence in decision makers to provide the needed funding.

From the outset, it should be clear whether the focus is on a single item or a package of items, i.e. the items under investigation need to be clearly defined. In some cases, an approach may be aimed at justifying the whole package. In other cases, justification may be provided for a single element of the package (e.g. all elements that are linked to monitoring, forecasting and warning).

An example of when justification may be focussed on a simple item is where it may be legally required. Here, compliance is imperative, and the only remaining issue is to ensure that the most cost-effective approach (see Section 16.3.2) is adopted. For example, preparedness and response have a strong need for adherence to health and safety requirements and in most countries, legal requirements are stipulated for this. The purchase of Personal Protective Equipment (PPE) – see Chapter 13 – such as hard hats, safety boots and gloves is therefore not a choice, but imperative. Furthermore, the PPE can also be used for non-flood hazard situations, providing additional benefits.

The remainder of the chapter explains in more detail the justification approaches shown in Figure 16.5.

16.3.1 Benefit-Cost Analysis

In the ideal situation a benefit-cost analysis is carried out to justify the needed components of a preparedness and response package. This implies that that it is essential to be able to assess the costs as well as the benefits in monetary terms.

Costs assessment

The costs assessment is quite straightforward and requires assessment of the following:

- Investment or capital costs.
- Operation and maintenance costs associated with the item, which may be assessed as a percentage of the capital cost per year.
- Lifespan of the resource.

- Residual value at the end of life.

Although the costs of items can be quite easily quantified, allocating joint costs among the beneficiaries if the benefits are multiple can be difficult. The required components for emergency management of flood defences may also have benefits in addressing non-flood related hazards. For example:

- Capability building (e.g. various types of training) may be independent of the hazard, hence costs of trainer, training centre etc can be shared.
- Resources: pumping capacity can be used for flood fighting as well as for managing drought or fires.

There are different methods for joint cost allocation in such situations, see e.g. WMO (2007). An useful approach is that of separable cost – remaining benefits (SCRB), as adopted, for example, by the US Department of Agriculture Forest Service.

Benefits assessment

In simple terms, the benefits are the values of the reduced expected flood damages and avoided fatalities that can be attributed to the (incremental) preparedness and response that is put in place. Apart from needing to distinguish between direct and indirect and tangible and intangible damages, assessing and valuing such benefits is complex (Molinari et al., 2013) and it will be important to explicitly state the underlying assumptions.

Often an item cannot be viewed (and justified) in isolation and needs to be packaged with other items as their effectiveness is dependent on the whole of a package. This is further complicated by the fact that preparedness and response also include an element of uncertainty. While a flood defence for example provides protection to a certain standard (and benefits can be quite easily calculated), the interdependencies and the operational nature of an emergency response, means that the impacts associated with the response are inherently uncertain (and thus also its benefits).

Approaches to benefit assessment - 'Willingness to pay' vs Expected Annual Damage

According to BCA principles, the benefits may be valued in terms of what people would be willing-to-pay for the reduction of the flood risk. This requires the use of hypothetical markets such as surveys which ask respondents directly for their willingness-to-pay (WTP) for flood risk reduction. In practice, this approach suffers from several problems, including problems related to the hypothetical characteristics of the valuation, risk communication, risk perception and high survey costs. For example, a study explaining why many individuals lack flood protection in the United States revealed that people have difficulties in fully understanding and evaluating flood risk, and tend to underestimate potential losses (Botzen et al., 2015).

In practice, therefore, damage models are used to estimate flood damage and flood risk. Since people tend to be risk-averse with respect to floods, the Expected Annual Damages (EAD) underestimates 'true' WTP. This can be solved using a Risk Premium (not to be confused with an insurance premium). Note that also flood fatalities can be valued based on WTP. This is the well-known concept of the Value of Statistical Life., Kind (2019) provides an extensive discussion on these topics.

To define the benefits, it is also important to understand the current economic baseline as well as the expected "step change" that can be attributed to the package of measures. This then allows comparison between:

- The risk reduction possible with the current preparedness and response infrastructure.
- The further risk reduction possible once the package of additional preparedness and response has been implemented.

Example using mobile barriers

In the event that a low stretch of flood defences could be raised using for example mobile barriers, the probability of flooding could be reduced, e.g. from 1/200 years to say 1/400 years, thus reducing the Annual Expected Damage. When assuming a life period of 15 years, one can calculate the aggregate benefits in time associated with such an intervention, based on

a certain discount rate. Based on the total length of the barriers (including their storage) needed, one can assess the present value of benefits and costs, ultimately resulting in a Net Present Value or Benefit-Cost Ratio.

As indicated before, the probability of flood events plays a significant role in assessing the benefits of preparedness and response. Benefits can be defined in terms of avoided Annual Expected Damages (AED). These can be determined for the current situation as well as for the future (say in 50 years), showing how the AED changes from year to year. Changes may include gradually increasing values to accommodate for climate change, soil subsidence (esp. in low-lying deltas) as well as population and economic growth.

BCA process

For carrying out a BCA aimed at assessing a preparedness and response package, it makes sense to use an **evaluation period** of say 10-15 years (much shorter than would be adopted for permanent civil engineering infrastructure). Going beyond 15 years is not realistic, since much of the equipment (e.g. early warning system software, mobile barriers) will have a limited lifespan and likely developments and innovations will result in new ways to approach preparedness and response. Also, residual risk may have changed due to adaptation and improvement of the flood defences themselves.

Using a suitable **discount percentage**, the present values of the streams of both costs and benefits can then be assessed and summed into a net present value and / or Benefit to Cost ratio.

The BCA approach can be enhanced using the parallel approaches presented in the following sections. For example:

- Through market research, various options can be assessed for each of the needed elements and a preferred (more cost-effective) option can be chosen (see Section 16.3.2). This can lead to defining alternative packages of measures, that each are subjected to the BCA.
- Multi-criteria analyses (Section 16.3.3) can also strengthen the BCA, by ensuring that other considerations are also included (e.g. enhanced sustainability by selecting more durable equipment).

Theoretical example of use of BCA

Benefit-Cost Analysis (BCA) is the traditional way of investigating the efficiency of investment in flood risk management measures, which can include emergency measures in response to an actual or threatened flood. Figure 16.6 illustrates the situation where five levels of investment are possible with different standards of flood risk reduction or emergency response.

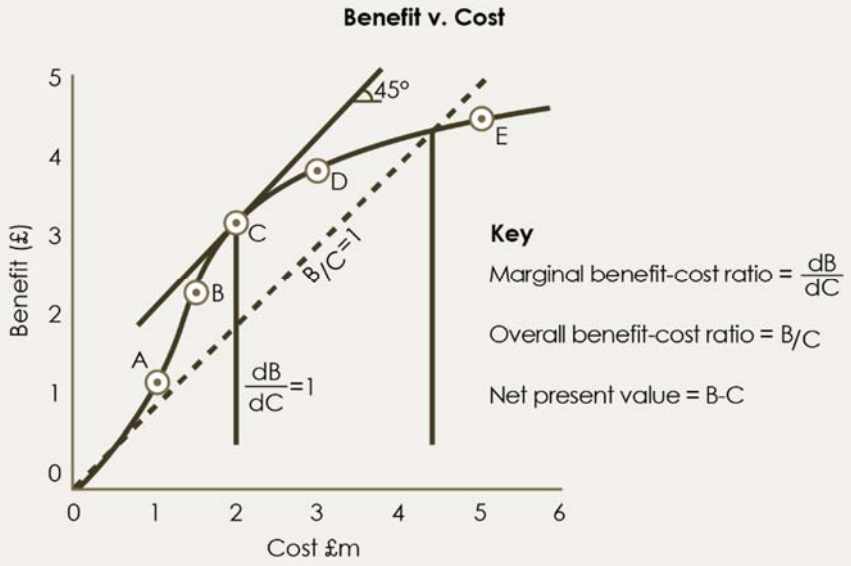

Figure 16.6: Benefit versus Cost (source: Flood Hazard Research Centre)

A comprehensive BCA suggests choices need to be made. The most expensive of these schemes comes at a total cost of £5.0 million and the least expensive is only just over £1.0 million.

The diagonal dotted line indicates the difference between schemes where benefits exceed costs (A, B, C & D). Of these the most economically

efficient is "C" as showing the greatest difference between benefits and costs (i.e. lying furthest from the diagonal, with the largest net present value). Investment levels necessary for scheme E are not justifiable in that costs exceed benefits. In a real-life example, the situation may be more complicated, but the diagram illustrates the principles involved.

Benefit cost analyses for a hydrometeorological networks

Parker (2008) identified a BCR of up to 40:1 for a totally new hydrometeorological network. In other words, the value of information was found to be forty times its costs of collection (initial investment, data collection and dissemination costs – communication system costs and maintenance cost).

Other authors have found that a BCR range of 5 to 10 is generally plausible for specific data needs for forecasting and warning. An example might be new stations added to the network to improve performances of an Early Warning System. For details see e.g. Pappenberger et al., (2015).

Benefit-cost of flood early warning systems on transboundary rivers

Pappenberger et al. (2015) demonstrated the benefit of cross-border flood early warning systems such as EFAS, the European Flood Awareness System. Continental and global forecasting models can help reduce flood risk, save lives and reduce the overall impact of severe events. The authors found BCRs of up to 400.

Benefits of improved lead times for forecasting and warning

Through comparison of the results of various case studies Parker et all (2009) demonstrated that improved lead time for forecasting and warning resulted in more time for preparedness and response and hence subsequent damage avoidance.

In municipalities possessing an experienced volunteer team and intervention centres, total savings could be between 5%-15%, because evacuation was the only effective measure.

For large rivers in which the warning time was over 24 hours, avoided damages could be between 28%-30% depending on the intervention measures used (Parker et al., 2007, 2008, 2009; Priest et al., 2011). In this case as evacuation of high-risk areas could be fully implemented using measures such as vertical evacuation, extending the protection of flood defences using mobile defences and using pumping to divert waters or to remove water from affected buildings. With such benefits, the associated costs of forecasting/warning systems can be easily justified.

16.3.2 Cost-Effectiveness Analysis

If benefits are too difficult to assess in monetary terms, cost-effectiveness analysis (CEA) may be used as the justification approach. A CEA identifies the option with the lowest (whole-life) cost of reaching an identified target or risk reduction level. This approach is very useful on an item by item (i.e. a certain piece of equipment) basis as opposed to a package basis (i.e. all items of the package).

Many of the basic principles highlighted regarding costs for BCA still apply here, i.e. investment costs, O&M costs, lifespan/assessment period and residual end of life value need to be made explicit. Obviously when comparing options, it makes sense that one ensures that the assessment period used for the analysis is the same for each option. If this is not possible, the annual costs (i.e. the sum of the annuity of the investment plus annual operation and maintenance cost) of the different options may be used to select the most cost-effective option.

Cost Effectiveness Analysis can therefore be very useful when comparing similar response measures or techniques (see Chapters 10 and 11) for ensuring the integrity of a flood defence Examples might include:

- Comparison of different types of mobile barriers.
- Comparison of different types of sandbags.
- Comparison of different types of pumps.

As already indicated in Section 16.3.1, a CEA can also be used to enhance or to supplement a BCA analysis. By carrying out a CEA

where there are various options, the most cost-effective options can be included in the package that is subsequently subjected to a BCA.

Cost effectiveness of different types of sandbags

As explained in Chapters 10 and 11, the sandbag is one of the more traditional and flexible measures used in flood emergency response. In the Netherlands a lot of research has been undertaken aimed at understanding which characteristics of sandbags are important as well as what the cost implications are.

Figure 16.7: Research on sandbag barriers in Flood Proof Holland, Delft, 2019 (courtesy: Eric Huijskes)

Regional water authorities have shared experiences and have subsequently teamed to investigate the cost-effectiveness of different types of sandbags. Sandbags come in various forms and shapes. They investigated the purchasing costs and various other properties of different types of sandbags including:

- UV-resistance.
- Friction resistance.
- Durability and sustainability.
- Multiple uses versus single use.
- Practical implementability considerations related to storage, filling, transportation, placing and removal.

Views about the options were also obtained from selected international organisations. Eventually, the most cost-effective sandbag was chosen.

16.3.3 Multi-Criteria Analysis or Qualitative analysis

If neither a BCA or a CEA are practical, a Multi-Criteria Analysis (MCA) may be the way forward. A MCA defines relevant criteria that need to be considered before taking a decision. Many more criteria can be considered that in BCA or CEA and the criteria can be quite diverse in nature, covering aspects such as:

- Environmental / sustainability.
- Ease of implementation.
- How fail-safe the solution is, given human error during implementation.

In the MCA the criteria can be weighted to reflect their relative importance and an approach to scoring defined (e.g. 1 to 10 for each criterion). The reader is kindly referred to literature on the use of MCAs.

Multi-Criteria Analysis by expert panel

A variant on MCA is to arrange for it to be completed by an expert panel (Doczi & Ross, 2014). To ensure robust and reliable findings, the panel should be made up of individuals from different organisations and with different expertise. The individuals should be open to different perspectives and have critical thinking skills. Open discussions within the panel should then yield a solid framework for the MCA (with agreed criteria, weighting and scoring systems), and subsequent sound

assessments of the various elements of the preparedness and response package that need to be appraised and justified.

Adherence to the Sendai Framework

An example of a qualitative analysis is the adherence to the Sendai Framework for Disaster Risk Reduction 2015-2030. Countries have signed up to the Sendai Framework, agreeing to concrete actions to protect development gains from the risk of disaster. Numerous items regarding preparedness and response that are relevant to this handbook can be linked to one of the four priority areas for action as identified in the Sendai Framework. By making this explicit, decision makers will understand – in a qualitative sense – the need for the items in question.

16.3.4 Benchmarking

Benchmarking is a powerful tool to justify what is potentially needed. By sharing information between similar organisations and putting this information into perspective (considering e.g. length of flood defences, flood probability, risk), similarities and/or dissimilarities can be identified. Suggestions of parameters that can be compared and would be useful in reaching relevant conclusions are given in Table 16.2.

Such an overview typically sparks discussions, increasing our understanding whether a flood defence manager is (potentially) missing resources or may even have too much.

Netherlands regional water authorities benchmarking initiative

In the Netherlands an initiative was launched in 2016 to obtain an overview of resources that were in place for all 21 regional water authorities. This was first published in 2016 (Unie van Waterschappen, 2016) and provided a better understanding of what is potentially needed per organization. Similar actions were also undertaken within the national water agency (Rijkswaterstaat) and within the Ministry of Defence, hence providing a national overview.

Table 16.2: Example of parameters for benchmarking

ASPECT	Unit
Parameters that characterize the residual risk and nature of flooding	
Residual risk (Annual Expected Damage)	US $
Number of properties at risk at T = 100 years	no
Number of people at risk at T = 100 years	no
Kilometres of flood defences – rivers	Km
Kilometres of flood defences – coast	Km
Kilometres of flood defences – lakes	Km
Response of system (< 1 day / 1-2 days / > 2 days / combinations)	
Parameters that characterize the resources and capabilities for emergency response to address the residual risk	
Number of flood defence manager staff involved in emergency response in general	No
Number of flood defence manager staff involved in emergency response linked to flood defences	No
Number of rapid intervention centres	No
Number of storage warehouses	No
Number of mobile barriers	Km
Number of sandbags available	No
Number of big bags available	No
Number of pumps (< 0.5 m3/s)	No
Number of pumps (> 0.5 m3/s)	No
Estimated dedicated annual budget for emergency response linked to flood defences	US $

16.4 Setting priorities

Section 16.3 provided guidance as to how funding for preparedness and response measures for emergency management of flood defences can be justified.

However, every flood defence manager is confronted with limitations in budgets that are made available, whether on an annual basis or as emergency funding. Such limitations mean that spending and investment decisions and their justifications need to be modified as short-term needs affect essential long-term plans. Deterioration of flood defence assets, the availability and quality of preparedness and response resources and capabilities and changes in risk profile, often result in difficult choices as what to do and which priorities to make:

- Where countries (e.g. Singapore or the Netherlands) have high flood protection standards, priorities are often focused on efficiency and effectiveness of the preparedness and response organization and infrastructure. In such cases, significant funds are aimed at research and knowledge sharing.
- Where countries (e.g. Mozambique) have generally lower standards of protection, limited funds and resources are unlikely to directed towards avoiding failure of defences. Instead, available funds are more likely to be directed towards early warning systems, which are easier to fund and resource and save lives by timely evacuation.

Thus, when setting priorities, there are always tensions between short-term and long-term goals:

- Long-term goals are likely to be focussed on ensuring the organization and associated preparedness and response resources and capabilities become more mature by:
  - ensuring the (basic) infrastructure and organization is in place,
  - moving towards systematic approaches
  - developing learning organisations, with plan-do-check-act cycles and knowledge sharing
- The short-term goals are likely to be connected with ensuring that investments focus on elements that benefits analysis has shown to be most critical to the success of subsequent actions. Certain elements in the benefits chain are preconditional to the success of other elements and this chain needs to be understood properly if priorities are to be set. Moreover, as needs are likely to be location-specific, they will vary from one location to another.

National long-term goals in the Netherlands

In The Netherlands significant research is undertaken to ensure preparedness and response is effective and efficient. Research has shown that failure of defences in the Dutch situation can be avoided in 80% of the cases if the anomaly (e.g. crack, erosion, displacement) in the flood defence is detected on time. See discussion of defence reliability in Chapter 14. Other factors are less important and hence in the Netherlands there is a strong drive to improve inspections, resulting in the development (for example) of new inspection techniques and of apps for recording and analysis.

Local short-term goals along River Severn, United Kingdom

Along the River Severn, prioritising the funding and installation of mobile barriers was not considered worthwhile unless there was not an adequate early warning system in place. Without warning, how would the responder know when, where and how to respond?

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CHAPTER 17

Making it work

Key messages:

- **Use the handbook actively**
- **Consider evaluating maturity levels**
- **Ask the handbook community for help**

	1.	Introduction
Overview Including Governance	2.	Emergency management of flood defences
	3.	Preparedness
	4.	Response
Focus Areas	5.	Flood threats
	6.	Flood defences
Details of Processes and Activities	7.	Communicating for emergency management
	8.	Assessing and inspecting
	9.	Understanding the problem
	10.	Selecting and designing measures
	11.	Techniques for emergency measures
	12.	Logistics and implementation
	13.	Health, safety and wellbeing
	14.	Reliability of emergency measures
Supporting Essentials	15.	Sharing knowledge and collaborating
	16.	Justifying the required funding
	17.	Making it work

Figure 17.1: Structure of the handbook

Other places to find information on the topics of this chapter

Chapter 15: the concept of levels of maturity and how this can help the flood asset manager

Chapter 16: an example of the concept of levels of maturity and how this can help the flood asset manager to justify needs

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Note:

The Reader is kindly requested to take note of the Disclaimer on page ii of this handbook.

Chapter title page photograph:

Exercise implementing erosion protection along the inner slope of an embankment of the River IJssel in The Netherlands (courtesy: Eric Huijskes)

Key messages:

- **Use the handbook actively**. The readers of the handbook are encouraged to actively use the handbook. Share your experiences in using it.
- **Consider evaluating maturity levels**. The concept of maturity levels can be a way to put matters in perspective and help you improve your practice.
- **Ask the handbook community for help**. The community linked to this handbook can help, please reach out!

17.1 It does not end here

Throughout the world we have built defences to various standards of protection, to avoid damages and loss of life. To ensure these defences stay intact or even are enhanced during an upcoming potential flood event, emergency management of flood defences is critical. This handbook provides details on the overall preparedness and response process, from warning to detection, to understanding failure mechanisms, such that emergency measures can be selected and put in place. In addition, overarching aspects such as governance, knowledge management and funding as well as practical aspects such as health, safety and wellbeing have been elaborated. For each of these steps and related aspects, the main principles, issues, methods and examples have been provided.

With an anticipated increase in the number of events that require an intervention, it is expected that this handbook will be needed more and more. All involved in this handbook are fully aware that the contents of the handbook will have to evolve in time. Lessons from emergencies, new knowledge gaps, innovations all need to be identified and incorporated in future versions of the handbook. By sharing experiences, possibilities for updates to the current handbook will emerge.

The preparation of this handbook has involved many professionals from different countries and organisations. The journey to arrive at what you are now reading has been inspiring and rewarding. The main partners behind the handbook, Rijkswaterstaat, Environment Agency, USACE and MLIT, have made use of this energy and have joined forces to initiate a Community of Practice (CoP) for emergency management of flood defences. The objective of this CoP is to develop, share and benchmark knowledge, experience and tools/approaches. The CoP will become a vehicle to identify ways in which to keep the handbook up to date, as well as to ensure that all within the community can readily find each other and have helpful interactions.

If you are interested in joining forces, please do reach out to:

IHEMFD@rws.nl

17.2 Encouragement

Reading the handbook and just absorbing its contents will not be sufficient. It is recommended to actively use the handbook. Take any of the chapters and try to define what the contents of the chapter mean for your organisation. In Chapter 15 the concept of maturity levels is introduced. This concept (see CEATI, 2018) can be used to define the various resources and capabilities that need to be in place as well as define the various levels of maturity per resource or capability. Two examples of applying such an approach are shown in the textboxes below.

Example 1 – High level Maturity Levels

In 2016 a large-scale exercise was held at Marken, The Netherlands. Rijkswaterstaat and various other partners, including Regional Water Authoritties, Municipalities, Safety Regions, Ministry of Defence and the Red Cross were all involved in this exercise called Waterwolf to save Marken from flooding, 100 years after its actual flooding. The USACE as well as Environment Agency attended as observers. After the exercise a workshop was organised, where the most important topics related to preparedness and response were identified and all three organisations (Rijkswaterstaat, USACE and Environment Agency) defined levels of maturity for each of the 11 most important topics identified. The scale of maturity covered five levels in each case. Once these levels were determined, each organisation assessed at which level they stood. This highlighted opportunities where one could learn from the other. This workshop, which lasted 4 hours, provided the basis for three organisations to learn from each other ever since. This has been formalised in the Levee Safety Partnership.

Example 2 – Specific Maturity Levels

In 2020, two Dutch Waterboards asked themselves whether they would be ready for the challenge, should a flood event hit their area. Both decided to use the concept of Maturity Levels to define what needs to be in place (i.e. resources and capabilities) and subsequently which levels of maturity can be defined. In total 27 resources and capabilities were identified, including response planning, inspections, understanding your assets, response measures, working safely, training, exercises, experience, etc. For each of these 27 items, between 2 and 5 levels of maturity were defined. Both waterboards spent two workshops to define and agree on the descriptions of the levels. The result of this process was four A3 sheets, in which a matrix of resources and capabilities versus their levels were set out (see screen dump in Figure 17.2)

No	Dimension	Level 1	Level 2	Level 3	Level 4	Level 5
1.1	We know the current strength of the flood defence					
1.1.1	Assessment	Assessment with a simple test and based on administrator's opinion.	Assessment also based on detailed test	Assessment based on Tailor-made assessment.	For all routes, there is also a prioritisation with regard to any emergency measures that may be required	
1.1.2	D… t… y…	Regular inspections are carried out	We act proactively and we know where typical bottlenecks arise throughout the year	Risk-based inspections are carried out.		
1.1.3	R… …n	Dominant failure mechanism has been explicitly mapped out for all trajectories	We derived fragility curves for the priority dike sections	We derived fragility curves for all dike sections	We have updated the fragility curves by means of measurements (experience	The current real-time …ength is visible via our …oard and is part of … …peration
1.2	W… …con					
1.2.1	M… r…	…been developed for flood defence structures	…have been developed for flood defences	…for the application of the control measures, including the establishment of prioritisation	…whether the organisation is in a position to implement all management measures.	
1.3	W… …d on the flood defence					
1.3.1	C… …)	The organisation has the expectations of the WMCN	The signalling and exceedance values have been carefully selected	The organisation clearly knows how to deal with uncertainties in expectations		
1.3.2	I… …l	The organisation has the expectations of its own operational organisation for water management	The signalling and exceedance values have been carefully selected	The organisation clearly knows how to deal with uncertainties in expectations		
1.4	W… …ks and the context in which we have to act					
1.4.1	Risico… …ntext	The organisation has an overall picture of the risks and the context of the underlying area.	Critical infrastructure and evacuation routes have been inventoried.	A prioritisation has been established, for example in relation to critical infrastructure or in relation to evacuation routes.		

Figure 17.2: Visualisation of maturity levels

This handbook deliberately does not prescribe standards or levels for resources and capabilities explicitly here. Rather, it is recommended that each organisation assesses what they believe they have already and what is required to improve their situation and performance. This assessment can be done within an organisation, only involving its own staff, but it can also be done jointly with other (peer) organisations as shown in the call-out boxes. To assist organisations in defining and assessing their levels of maturity the stepped approach shown in Figure 17.3 is recommended.

Figure 17.3: Steps to define and assess levels of maturity

17.3 Future of the handbook

The handbook will be on the internet for the years to come and can be accessed free of charge. In the short term, i.e. for the large part of 2025, the handbook will be temporarily hosted at the following site on the internet:

The handbook can be found at: www.rijkswaterstaat.nl/en/handbook

No doubt the Community of Practice will continue to identify new opportunities to improve on the handbook. The validity and relevance of its contents will depend on this energy. We kindly ask all that use the handbook to provide any feedback they can give regarding the contents of the handbook.

17.4 Reference

CEATI (2018). Dam Safety Maturity Matrix. Information available at https://www.ceati.com/programs/dam-safety#:~:text=The%20Dam%20Safety%20Maturity%20Matrix,safety%20program%20against%20industry%20practice

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Glossary

Actor A participant in an action or process.

Alarm level The level below crisis level. This is usually a predetermined value where the monitored levee parameter falls to within range of the crisis level but has not resulted in systematic failure of the function being monitored. See also Crisis level

Animal burrow A tunnel or hole in the ground dug by an animal that seeks habitation or temporary refuge.

Annual exceedance probability Probability of exceeding a specified flow or level in any year (inverse of the return period for an annual maximum series)

Anomaly Something that deviates from what is standard or expected.

Asphalt Description of all mixtures of mineral aggregates bound with bituminous materials used in the construction and maintenance of paved surfaces.

Assessment The process of identifying, quantifying, and prioritising the condition, vulnerability, or risk associated with a system or components of a system.

Asset Person, structure, facility, information, material or process that has value. Generally, in this handbook, an asset is a raised defence, a structure, a watercourse, a channel, a culvert or a beach. Mainly during risk assessment, it can also indicate anything in the flood area that has value.

Asset management Systematic and co-ordinated activities through which an organisation optimally and sustainably manages its assets and asset systems. This includes their associated performance, risk and expenditures over their life cycles for the purpose of achieving the organisations' strategic aims.

Awareness The state of having knowledge about something.

Backwards erosion piping The creation of flow channels within a levee or the underlying ground as a result of seepage and continuing internal erosion. Piping can lead to the development of boils or breaches.

Bathymetry The information derived from measurement of water depth at various places in a body of water.

Berm A horizontal step in the sloping profile of a levee.

See also Bench

Blanket layer layer covering a sandy aquifer at the landside of a flood embankment

Breach Any loss of material such that water could or does pass through the structure. See also Deterioration, Break, Failure, Progressive failure, Sudden failure

Breakwater Structures constructed on the coastline as part of a coastal defence system or to protect beaches and/or harbours from the effects of wave action, coastal erosion or longshore drift. They can be constructed some distance from the coast, or with one end linked to the coast. They can be either fixed or floating. A breakwater structure is designed to absorb the energy of impacting waves. This is done either by using mass (e.g. with caissons) or by

	using a revetment slope (e.g. with rock or concrete armour units)
Catchment	The area from which precipitation and groundwater will collect and contribute to the flow of a specific river. (US equivalent is 'Watershed')
Caving	Process of losing material from a stream or riverbank caused by different types of erosion. See also *External erosion, Internal erosion, Scouring*
Clay	A stiff, sticky sedimentary material that is soft and pliable when wet and consists mainly of various silicates of aluminium. Clay particles are smaller than silt, having a diameter less than 0.0039 mm. They possess electromagnetic properties that bind the grains together to give a bulk strength or cohesion
Closure structure	A structure intended to keep water from entering a leveed area, such as stop logs, earthen closure, gate or sandbag closure. The structure may be permanent or temporary.
Coastal defences	General term used to encompass both coast protection against erosion and sea defence against flooding.
Consequence of failure	The (sum of) personal injuries, fatalities, material damage, environmental damages and other damages (e.g. cultural heritage) due to the failure of a structure or a flood defence system
Contact erosion	Internal erosion at the joint of two soil materials
Core	1). An inner, often much less permeable, portion of a structure (e.g. a levee). The fines content and upper sizes may be controlled. 2). A cylindrical sample of rock or soil extracted by coring
Crack	A narrow break in the continuity of the material
Creep	Time dependent deformations that occur in soil at constant effective stress without changes in volume and pore water pressure.
Crest	Highest elevation of flood defence (levee, flood wall, etc.)
Crown	The top, horizontal portion of a flood embankment that is commonly used for access
Crisis management	Crisis management refers to the identification of a threat to an organization and its stakeholders in order to mount an effective response to it.
Cross-section	Vertical section of the levee perpendicular to the levee course/line. It includes outside and inside sections and is measured by surveying elevations with ranges across the levee from landside to riverside. Also depicts the shape of a watercourse by surveying elevations across and perpendicular to the direction of flow
Culvert	A closed conduit carrying a watercourse beneath an obstruction such as a road, railway or canal. The term 'closed' implies that a culvert has a hard soffit and invert. The term conduit implies the conveyance of water some or all of the time, but excluding tunnels and underpasses for vehicles, pedestrians and animals

Current Body of water that has a steady flow in a particular direction.

See also *Flow*, *Discharge*

Cut-off wall A wall of impervious material usually of concrete, asphaltic concrete, or steel sheet piling constructed in the foundation to reduce seepage beneath and adjacent to the levee

Dam An artificial barrier, usually built across rivers, river mouths and estuaries, with the ability to retain or impound water or liquid-borne materials for control and storage purpose

Damage potential Property, goods etc that would be destroyed, damaged or affected in the case of potential flooding

Debris The remains of anything broken down or destroyed, or pieces of unwanted material and trash.

Degradation An irreversible process leading to a significant change in the structure of a material, typically characterised by a loss of properties (e.g. integrity, molecular mass or structure, mechanical strength) and/or by fragmentation. Degradation is affected by environmental conditions and proceeds over a period of time comprising one or more steps.

See also *Deterioration.*

Demountable defence Defences built above ground and supported by in situ structural foundations as part of a flood defence system. These are not normally in place but are put in place during a flood event or another event, for example to close a gate or to raise a levee.

Deterioration 1). A gradual decline, as in quality, serviceability or strength

2). Decline in the material properties of some or all components of an asset caused by external agents (e.g. freeze/thaw) leading to a reduction in its structural strength.

See also *Degradation.*

Dewatering The removal of groundwater/surface water to lower the water table.

See also *Drainage*

Diagnosis Identification of the possible cause(s) of a failure or deterioration of a function, based on logical reasoning founded on a set of information coming from an inspection, a control or a test. By extension, a statement or conclusion from such an analysis

Digital terrain model A digital representation of ground surface topography or terrain exclusive of features (the earth surface).

Synonym: Digital terrain models

Dike/Dyke Flood protection linear structure that can be geotechnical works (levee), masonry, or concrete structure (flood wall). Also relates to sea dikes (breakwater) or the dikes along a canal or the auxiliary structure associated with a dam that serves to retain the reservoir. Also relates to river training structures. These structures are typically constructed using rock.

Discharge The ratio of total volume of water flowing to a particular unit of time, normally expressed in cubic metres per second (m^3/s).

Synonym: flow rate (often abbreviated as flow).

Disinformation False information that is intended to manipulate, cause damage, or guide people, organisations and countries in the wrong direction. See also *Misinformation.*

Drain Part of a hydraulic structure whose function is to get water out of or across the structure. It can be made from coarse geotechnical material (or coarser than the rest of the body) or from geosynthetic materials. In a masonry or concrete structure, it can consist of a boring (hole).

Drainage Process of dewatering a soil body, a structure, or a levee.

Removal of naturally occurring runoff from a watershed or basin by a waterway (canal, channel, or other conveyance mechanism).

Drainage area Measured area within a drainage divide that contributes surface runoff to a given point on a stream.

Synonym: *watershed*

Drainage ditch Ditch parallel to the levee on the landside toe, collecting and discharging the seepage water

Early warning (system) Detect and inform at-risk communities before disasters, enable early action, save lives and reduce impact of disasters.

Earth fill Natural earth materials that can be placed and compacted by construction equipment

Emergency Management Process that helps organisations to identify and respond to potential emergencies that can affect their operations, reputation, and/or the public. It includes several sub-processes, including initiation, early warning, inspections, failure mechanisms, response strategies, and post-response activities, all of which aim to minimize negative impacts and ensure successful recovery.

Embankment Fill material, usually earth or rock, placed with sloping sides and with a length greater than its height.

Encroachment Any permitted, authorised, or unauthorised structure that is within the easement area of the flood risk mitigation device and is not a part of the device itself.

Escape route Way to leave the polder/hinterland in the case of emergency (emerging levee failure). Must also be usable during flooding of the landside area behind the levee.

Estuary A transition zone between river environments and maritime environments subject to both marine influences, such as tides, waves, and the influx of saline water; and riverine influences, such as flows of fresh water and sediment.

Event An occurrence or meeting of specified conditions (e.g. water level, wave height and period) in relation with the characteristics of the flood defences. By extension, the result of these conditions on the landside area (e.g. volume of water overtopping or overflowing, water depth, velocity of the current).

External erosion Process by which particles are removed from a surface by the action of wind, flowing water or waves. See also *Caving, External erosion.*

Failure

Gradual decline (deterioration) or sudden decline (break) of the structure of a levee or of its foundation, leading to the inability to achieve its function. See also Failure modes, Deterioration, Break, Breach

Inability to achieve a defined performance threshold for a given function, in particular for flood defence.

Failure mechanism

The catalyst and physical path to failure.

Failure modes

Description of one of any number of ways in which a levee or flood defence system may fail to meet a particular performance indicator

Failure probability

Measure of chance that failure will occur. Typically defined as the relative frequency of occurrence of that event out of all possible events and expressed as a percentage with reference to a time period. An example would be a one percent annual exceedance probability.

Filter

Layer or zone consisting of geotextile, geomembrane, sand, gravel, or other granular or fibrous material, preventing the fine materials from being washed through the voids of another layer or to avoid particle transport in the case of seepage.

Flood

Discharge of water beyond the mean discharge under conditions of high-water level. A flood is described by its probability of not being exceeded, its hydrograph, max discharge, duration, and volume.

An inundation (by overflowing or overtopping) that comes from a river, a sea or other body of water and causes or threatens damage. Also, any relatively high stream flow overflowing or overtopping the natural or artificial banks in any reach of a stream.

Note: These definitions of flood exclude those types of flooding (fluvial, groundwater) not managed by flood defences.

Flood defence asset

An asset (e.g. levee, flood wall, other raised defence, closure structure, pumping station) that would by its failure increase the likelihood of flooding from any main river and/or the sea to people, property or infrastructure.

Flood-defence manager

Individual responsible for managing flood risk by the operation and maintenance of local flood defences.

Flood defence system

The system of levees and associated structures that protects a previously system floodable area from floods up to certain condition

Flood gate

1). A roadway or railroad closure structure that can be of varying types, e.g. swing gate, trolley gate and rolling gate. See also Closure structure

2). A means of controlling, varying or stopping a flow in a pipeline. They can be of different sorts (e.g. sluice gate or flap gate) and be housed in a gate well.

Floodplain

Land on either side of a river or behind the coastal defences that is below the highest defined flood level.

Flood risk

A measure of the combination of the likelihood of flooding occurring and the associated impacts on people, the economy and the environment. Often expressed in probability of occurrence per year.

Flood risk management Flood risk management (FRM) is the systematic application of management policies, procedures and practices to the tasks of identifying, analysing, assessing, treating and monitoring flood risk.

Flood season Time of year when flooding is more likely to occur.

Floodplain Land on either side of a river or behind the coastal defences that is below the highest defined flood level.

Flow See *Discharge*

Fluvial Relating to a stream or river. Produced by the action of a stream.

Forecasting The process of making statements about events whose actual outcomes (typically) have not yet been observed. A commonplace example might be estimation of the expected value for some variable of interest at some specified future date.

Foreshore The part of a shore between high- and low-water marks.

Foundation A component of an engineered structure that transmits a structure's forces into the underlying soil or rock. Related to levees, the levee generally rests directly on the ground without an engineered foundation, where the ground itself is the foundations. In some case, particularly if the soil has poor properties, then a blanket (e.g. Fascine mattress) can be used as foundation

Fragility The likelihood of particular defence or system to fail under a given load condition. Typically expressed as a 'fragility curve' relating load to likelihood of failure. Combined with descriptors of deterioration, fragility relationships enable performance to be described over time

Freeboard 1). The height of the lowest point of a structure above still water level at the maximum level of a given event. 2). The increment of levee or flood wall height added to the design flood height to increase the likelihood of the design event being contained without the levee or flood wall overtopping.

Geotextile Any strong synthetic fabric used in civil engineering, as to retain an embankment to stabilise soils, retain soils, prevent the mixing of dissimilar soils, provide a filtering function, pavement support, subgrade reinforcement, drainage, erosion control and silt containment.

Governance Governance is the way the rules, norms and actions are structured, sustained, regulated and held accountable. The degree of formality depends on the internal rules of a given organization and, externally, with its business partners. As such, governance may take many forms, driven by many different motivations and with many different results

Hazard A process, phenomenon or human activity that may cause loss of life, injury or other health impacts, property damage, social and economic disruption or environmental degradation

A situation, physical event (e.g. flood or storm), phenomenon or human activity with the potential to result in harm.

Probability for a dangerous phenomenon to occur with a given intensity.

Hinterland	The area behind the coast or the banks of major rivers.
Incident	An anomalous situation which must be managed and is outside of a (previously defined) normal/expected range of loading and/or performance.
Infrastructure	Collective term for a group of assets needed for the operation of a society or enterprise or the services and facilities necessary for an economy to function. It includes physical resources, services and information technology facilities, networks and assets that, if they were disrupted or destroyed, would have a serious effect on the health, safety, security or economic well-being of citizens or the effective functioning of government. Examples include roads, railways, public services, power supplies and telecom equipment
Inspection	An examination of the structure of an asset by a specially trained person
Internal erosion	The movement of soil particles as a result of chemical actions and/or unbalanced seepage forces produced by percolating water. See also *Caving, Internal erosion.*
Inundation	See *Flood*
I-wall	Sheet pile driven vertically into the ground.
Landside	Refers to the side of the flood defence structure opposite to the waterside. Antonym: Waterside
Lead time	The amount of time between the release of a forecast and the occurrence of the predicted phenomena
Levee	Raised, predominantly earth, man-made structures with primary objective to provide protection against flood events along (low-lying) coasts, rivers, lakes and artificial waterways. Levees are structures that are not designed to be reshaped by natural actions such as current or wave and wind action, in this way excluding dunes.
Levee segment	The division of a levee based on some determined parameter such as ownership, composition etc
Leveed area	Area behind the levee that is not flooded, or in which the flooding is reduced or delayed due to the levee/flood defence system
Level of protection	For a levee: the maximum event that, with a high degree of assurance, will not result in levee failure subsequently inundating the leveed area. This maximum event can be associated with a probability of occurrence. For a flood defence system: the maximum event that, with a high degree of assurance, will not result in defence system failure subsequently inundating the flood defence area. This maximum event can be associated with a probability of occurrence.
Limit state	1). Conditions under which a structure can no longer perform its intended functions. 2). The boundary between safety and failure for a structure. The limit state function Z=R-S is a function of the structure's strength (R) and loading (S) for a particular failure mode. Failure will not occur if the limit state function is positive. Generally two types of limits state are distinguished: ultimate limit states

	(ULSs) are related to the safety of the structure and they define the limits for its total or partial collapse. Serviceability limit states (SLSs) represent those conditions that adversely affect the expected performance of the structure under normal service loads.
Liquefaction	Describes a phenomenon whereby a saturated soil substantially loses strength and stiffness in response to an applied stress, usually earthquake shaking or other sudden change in stress condition, causing it to behave like a liquid.
Macro-stability	The resistance to global shear failure of a structure and its foundation
Maintenance	All activities whose purposes are to maintain or restore a system in a state or in given safety or working condition, to perform a required function. It includes preventative maintenance and repairs (exclusive options). Generally, it consists in repairing or replacing the components of a structure whose life is less than that of the overall structure, or of a localised area that has failed or will fail
Mechanism	The fundamental processes involved in or responsible for an action, reaction, or other natural phenomenon (these mechanisms can lead to breach, collapse, settlement and other failures modes)
Meteo	Weather forecasting
Misinformation	False information provided without an intention to cause harm. See also *Disinformation*
Monitoring	Systematic recording over time to establish trends in data.
Monte-Carlo simulation	Monte Carlo simulation (also referred to as MC simulation or Monte Carlo study) is a stochastic or probabilistic method wherein random samples from parameter distributions are drawn through random experiments. Calculations with these samples iteratively arrive at the statistically expected value for an output calculation.
Operation	The day-to-day activities, associated with the flood defence management, exclusive of the maintenance itself
Overflowing	Passing of water over the top of a structure as a result of a water level higher than the crest of the structure. See also *Overtopping*
Overtopping	Passing of water over the top of a structure as a result of wave action, surge or wind. The water level in front of the structure is lower than the crest level of the structure. See also *Overflowing*
Performance	The degree to which a system (e.g. a flood defence system), a structure (e.g. a levee) or a component succeeds when evaluated against some stated aim or objective.
Personal Protective Equipment	Clothing and equipment that is worn or used in order to provide protection against hazardous substances or environments Or Equipment used to prevent or minimize exposure to hazards
Piping	The creation of flow channels within a levee or the underlying ground as a result of seepage and continuing *internal erosion*. Piping can lead to the development of boils or breaches.

Polder A low-laying piece of land reclaimed from a sea, lake or river that forms an artificial hydrological entity.

Precipitation Precipitation is any liquid or frozen water that forms in the atmosphere and falls back to the earth. It comes in many forms, like rain, sleet, and snow.

Probabilistic Descriptor of method or process in which the variability of input values (e.g. asset loading and strength) and their sensitivity are taken into account to give results in the form of a range of probabilities for different outcomes (e.g. failure).

Probability Measure of the chance that an event will occur. Typically defined as the relative frequency of occurrence of that event out of all possible events and expressed as a percentage with reference to a time period e.g. one per cent annual exceedance probability.

Progressive failure Failure process where, once a threshold is exceeded, some residual strength enables the asset to maintain restricted performance while further progressive loss of strength takes place

Pumping station A structure used to evacuate water from interior drainage in a flood defence system.

Rehabilitation The process of restoring an asset for the purpose of returning that asset to design performance

Reinforcement The process of improving the performance of an asset (or one of its components) against an event or a degradation mechanism

Repair Restoring to operating condition after damage has occurred and a structure's functionality has been reduced. Repair can also be thought of as corrective maintenance.

Reservoir An artificial lake, basin or tank in which a large quantity of water can be stored

Residual risk The remaining level of risk at any time before, during and after a program of risk mitigation measures has been taken

Resilience The ability to adapt to changing conditions and prepare for, withstand, and rapidly recover from disruption.

Retaining wall Walls, usually constructed of concrete, rock, or sheet piles, which provide lateral stability of the earth, preventing the soil from sloughing or slope failure. Different types of retaining walls exist, e.g. gravity wall, counterfort wall, I-wall, T-wall

Return period For a given parameter (e.g. water level), the mean duration between two events where this parameter was observed. Inverse of the probability that a given event will occur in any one year. Annual exceedance probability (AEP) is the preferred term for flood risk management, one per cent AEP being equivalent to a 100-year return period. Synonyms: Recurrence period, Recurrence interval

Revetment Works to protect the slopes of a levee against erosion, typically constructed from armourstone, masonry, asphalt or concrete blocks.

Riparian Of, pertaining to, situated, or dwelling on the bank of a river or other body of water. A riparian zone or riparian area is the interface between land and a river or stream. Plant habitats and communities along the river margins and banks are called

	riparian vegetation, characterised by hydrophilic plants.
Risk	Risk is defined as being a function of the probability that an event will occur, and the consequence associated with that event. Risk = f (probability x consequence). A measure of the probability and severity of undesirable consequences or outcomes for the exposed entities or populations.
Risk analysis	Risk analysis is a decision-making framework that comprises three tasks – risk assessment, risk management, and risk communication.
River-basin	The ensemble of *catchment*s contributing to the flow of a specific river (or system of connected rivers)
Run-up, run-down	1). The rush of water up a structure or beach as a result of wave action. 2). The upper and lower levels reached by a wave on a beach or coastal structure, relative to still water level, measured vertically
Sand boil	…. Synonym: Sand volcano
Sandbag	A sack made of hessian/burlap, polypropylene or other materials that is filled with sand or soil.
Scenario	Account or synopsis of a possible course of action or events.
Scour	In a stream: erosion of the bed or banks of a watercourse by the action of moving water typically associated with channel contraction or local feature such as bridge pier. On the coast: erosion resulting from shear forces associated with flowing water and wave actions. See also *Caving*
Sea defence(s)	Works to prevent or alleviate flooding by the sea
Seepage	In soil engineering, the movement of water in soils. Seepage depends on several factors, including permeability of the soil and the pressure gradient.
Seepage berm	Construction of additional weight at the landside toe of the levee to counteract upward seepage forces and/or additional length required to reduce uplift pressures at the toe of the levee to tolerable values
Settlement	The downward movement of the ground surface or a structure on or in the ground as a result of external stresses.
Sheet pile	Interlocking panels of steel that are driven into the ground to provide lateral support.
Sill	1). A submerged structure across a river to control the water level upstream. See also Weir 2). The crest of a spillway
Sliding	1). Movement of a layer of materials along a slope or on a horizontal plane. Synonym: Sloughing 2). A result of excessive lateral earth pressures with relation to retaining wall resistance thereby causing the retaining wall system to move away (slide) from the soil it retains.
Slope	1). Inclined face of a cutting, bank or levee. 2). Amount of inclination of a surface or a line to the horizontal. It is a special case of the gradient in calculus where zero indicates gravitational level. A larger number indicates higher or steeper degree of 'tilt'. Often slope is calculated as a ratio of 'rise'

	to 'run', or as a fraction ('rise" over "run') in which run is the horizontal distance and rise is the vertical distance
Slope protection	A structure (e.g. rock or concrete) on the slope intended to protect the underlying material against erosion by current and/or wave action
Sluice	A water channel that is controlled at its head by a gate.
Spillway	A designed section of a levee with lower crest elevation, protected crest and slope, through which flow can be discharged in order to protect the levee system against failure by overflowing non-protected sections. Synonym: Safety spillway, Overflow, Levee overflow
Stake	1). A monetary or commercial interest, investment, share, or involvement in something, as in hope of gain. 2). A personal or emotional concern, interest, involvement, or share
Stakeholder	An individual or group with an interest in, or having an influence over, the success of a proposed project or other course of action
Stochastic	Having random variation in statistics
Stoplog	Timber or metal beams spanning horizontally between grooves in piers or abutments of a control structure, used to isolate part of the structure or related reach for maintenance, or to raise the elevation of water retained
Storm event	Event involving high winds, waves and/or river flows that may or may not cause a flood. See also *Event, Flood*
Storm surge	A rise of sea elevation caused by water piling up against a coast under the force of strong onshore winds such as those accompanying a hurricane or other intense storm. Reduced atmospheric pressure may contribute to rise. See also *Surge*
Structure	A constructed component using processed materials, such as concrete, masonry, armourstone, and steel, which is part of a flood protection system
Suffusion	The migration of soil particles through the soil matrix driven by flow through the soil. Suffusion is a contributor to the manifestation of internal erosion
Subsidence	Movement of the ground (mostly vertical) that is not caused by the application of an external load. Examples of subsidence include karst, internal erosion, the collapse of mine workings, settlement due to animal burrowing and desiccation shrinkage caused by seasonal moisture take by trees and other large vegetation.
Superiority	The variation in crest levels along a river flood defence in relation to the flood water levels in the river permitting overtopping of the defence at identifiable locations.
Surge	Changes in water level because of meteorological forcing (wind, high or low barometric pressure) causing a difference between the recorded water level and that predicted using harmonic analysis. Surge may be positive or negative. See also *Storm surge*

Tension crack Crack appearing at the surface of a soil mass, often adjacent to a retaining wall or top of a failing slope

Threat Refers in this handbook to *flood-related* threats posed to the integrity of a flood defence, either by contributing to the hydraulic load on a flood defence or by affecting the required emergency management. A lot of response actions are driven by the threat not the underlying hazard.

Tide Water movements that essentially are generated by the global response of oceans to astronomic effects. On the continental shelves and in coastal waters, particularly bays and estuaries, the effect is amplified by shallow water and coastal platforms

Toe The intersection of the landside or waterside slope of a levee with the ground surface.

Tolerance Engineering tolerance is the permissible limit of variation in a measured value or physical property of a material, manufactured object, system, or service. The tolerance may be specified as a factor or percentage of the nominal value, a maximum deviation from a nominal value, an explicit range of allowed values, be specified by a note or published standard with this information or be implied by the numeric accuracy of the nominal value.

Trigger A threshold level of a monitored parameter, which, if exceeded, indicates the need to make a change in the management process.

Tsunami Water waves caused by the displacement of a large body of water (ocean or large lake) with wavelengths in the order of minutes rather than seconds

Uncertainty Lack of sureness about someone or something ranging from almost complete sureness to almost complete lack of conviction about an outcome. Caused by (a) natural variability (inherent uncertainty) or (b) incomplete knowledge (epistemic uncertainty)

Uplift 1). Upward pressure in the pores of a material (interstitial pressure) or on the base of a structure.

2). The situation in which pore water pressure within a confined or semi-confined aquifer can exceed the total weight of the overlying soil or structure and lead to a failure caused by upward movement.

Vulnerability The susceptibility of people and assets in the leveed area to physical or emotional injury or damage during an event

Waterside Refers to the side of the flood protection structure towards the water. Antonym: Landside

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